TRANSVERSITY 2014, 9-13 June 2014, Chia, Cagliari, ITALY

INFN Physics Outlook

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INFN and Univ. of Padova

WHAT NEXT

In view of the complex landscape we have to confront, INFN has recently started a process to identify the most important research themes that we should focus on amongst those that in this moment do not receive enough attention (people, funding). FERRONI

HIGH ENERGY, HIGH-INTENSITY, ASTROPARTICLE PHYSICS COMPLEMENTARY ATTACK TO THE NEW PHYSICS FORTRESS

2012: the conquest of a new energy scale in physics

- ~1900 **ATOMIC SCALE** 10^{-8} cm. $1/(\alpha m_e)$
- ~1970 **STRONG SCALE** 10^{-13} cm. $Me^{-2\Pi/\alpha_s b}$
- ~2010 **WEAK SCALE** 10^{-17} cm. TeV^{-1}

FUNDAMENTAL OR **DERIVED SCALE**?

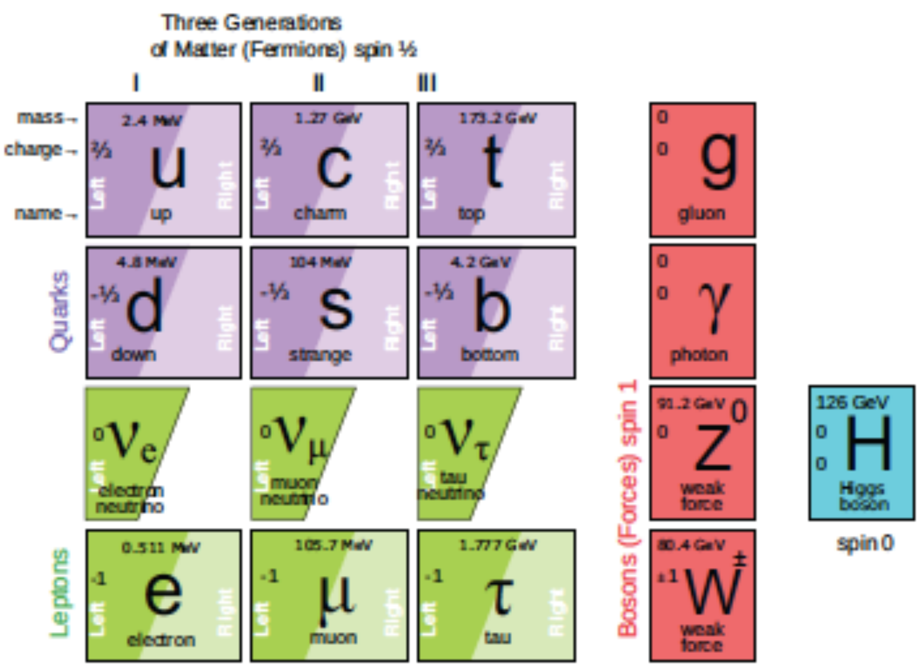
EX. **EXTRA-DIMENSIONS**
or
TeV STRING THEORY

EX.: **TECHNICOLOR** or
SUSY with ELW RAD. BREAKING

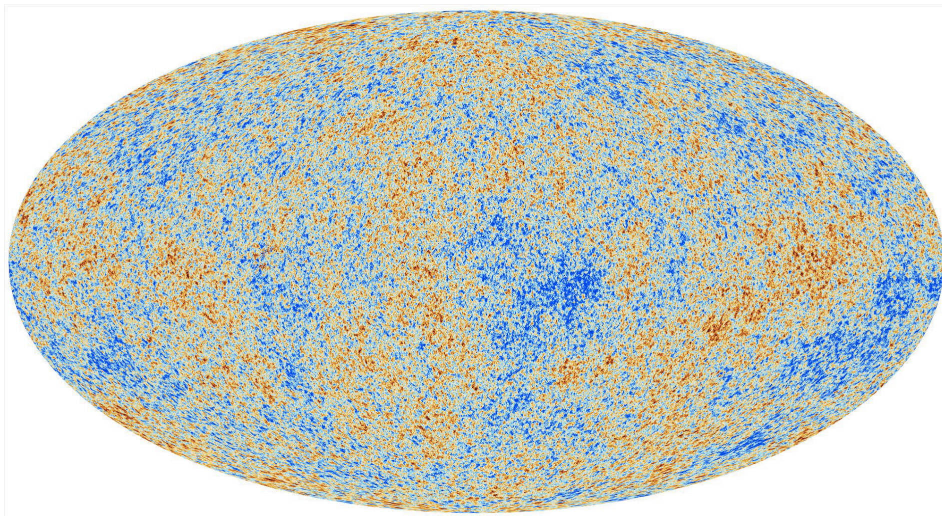
NEW PARTICLES AT THE TEV SCALE?

2013: the thiumph of the STANDARD

- **PARTICLE STANDARD MODEL**



- **COSMOLOGY STANDARD MODEL**



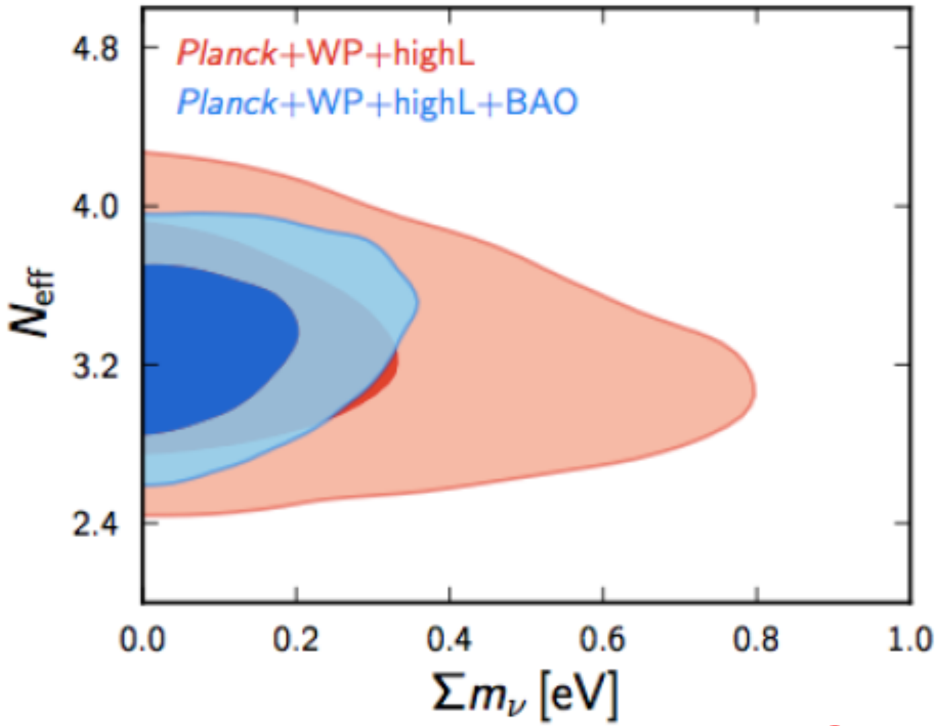
ΛCDM + "SIMPLE" INFLATION

$\Omega_\Lambda = 0.686 \pm 0.020$

$\Omega_m = 0.314 \pm 0.020$

$\Omega_b h^2 = 0.02207 \pm 0.00033$

$h = 0.674 \pm 0.014$



$N_{eff}=3.36\pm0.34$

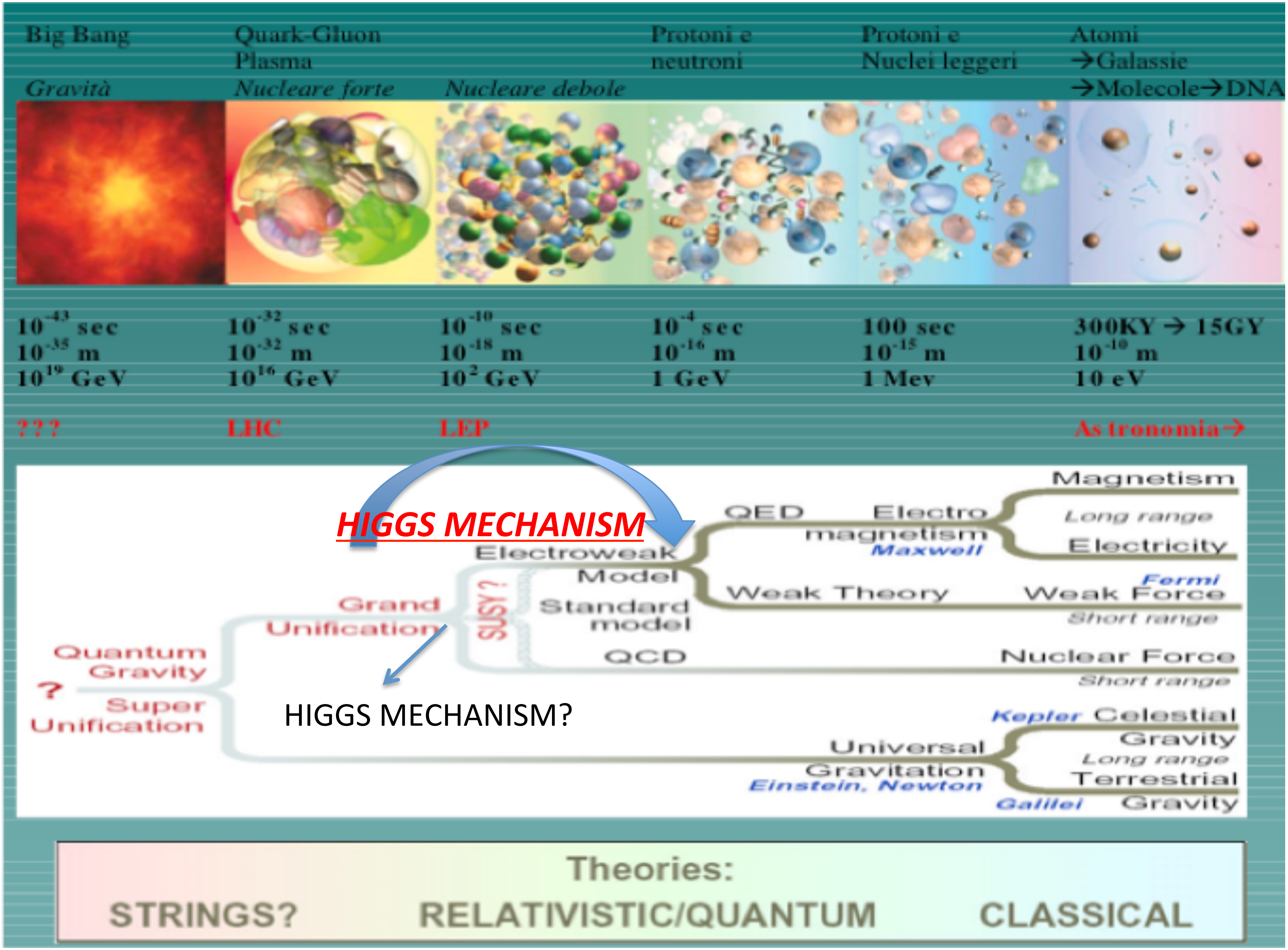
The extracted value of N_{eff} depends whether one makes use of the value of the Hubble parametr from the Planck data or from independent observations

$\Sigma m_\nu < 0.23- 0.8$ eV

Recent (and controversial!) **BICEP2** results: from the measurement of the B-mode polarization of the CMB photons → initial **inflationary epoch** at energies ~ **$V^{1/4}$ = 1.94 x 10^{16} GeV $(r/0.12)^{1/4}$**

r= ratio of the CMB tensorial/scalar components – from BICEP2 r ~0.2 , r≠0 at ~6 σ

INFLATON at ~ 10^{16} GeV, not standard Higgs inflation (see, however, Bezrukov and Shaposhnikov)



Big Bang
Gravità
Quark-Gluon Plasma
Nucleare forte
Nucleare debole
Protoni e neutroni
Protoni e Nuclei leggeri
Atomi →Galassie →Molecole→DNA
10^{-43} sec
10^{-35} m
10^{19} GeV
10^{-32} sec
10^{-32} m
10^{16} GeV
10^{-10} sec
10^{-18} m
10^{2} GeV
10^{-4} sec
10^{-16} m
1 GeV
100 sec
10^{-15} m
1 Mev
300KY → 15GY
10^{-10} m
10 eV
???
LHC
LEP
Astronomia→
HIGGS MECHANISM
Magnetism
QED
Electro magnetism
Maxwell
Long range
Electricity
Electroweak Model
Standard model
SUSY ?
Weak Theory
Fermi
Weak Force
Short range
Grand Unification
Quantum Gravity
?
Super Unification
QCD
Nuclear Force
Short range
HIGGS MECHANISM?
Kepler
Celestial Gravity
Long range
Universal Gravitation
Einstein, Newton
Terrestrial Gravity
Galilei
Theories:
STRINGS?
RELATIVISTIC/QUANTUM
CLASSICAL

MICRO

MACRO

GWS STANDARD MODEL

HOT BIG BANG STANDARD MODEL

UNIVERSE EXPANSION +

WEAK INTERACTIONS

1 sec. after BB

NUCLEOYINTHESIS

NUMBER OF BARYONS and **OF NEUTRINO SPECIES** → CONFIRMED FROM CMB **350000 YEARS** AFTER BB

BUT ALSO

FRICTION POINTS

-COSMIC MATTER-ANTIMATTER ASYMMETRY

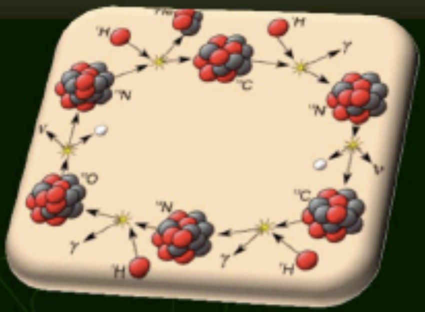
-INFLATION ???

- DARK MATTER + DARK ENERGY

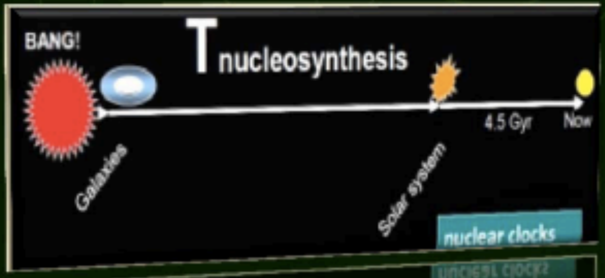
OBSERVATIONAL EVIDENCE OF NEW PHYSICS

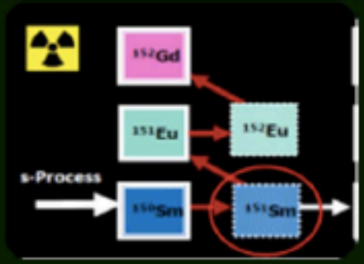
BEYOND THE STANDARD

L4 - Nuclear Astrophysics and Interdisciplinary Research



- Reactions @ stellar energy
  - Nucleosynstesis
  - LUNA@LNGS, ASFIN@LNS and ERNA
- n-capture for astrophysics and reactor applications
  - N_TOF @CERN
- Annihilation of anti-protons in nuclei in nuclei 5keV – 5 MeV region of cosmological interest
  - ASACUSA @CERN
- Pauli principle violation in atomic transitions
  - VIP @LNGS
- Gravity effects on antimatter
  - AEGIS @CERN





^{3}He (^{3}He,2p)^{4}He: σ down to 16 keV

C. BROGGINI 2013

no resonance within the solar Gamow Peak

^{3}He(α,g)^{7}Be: ^{7}Be ≈ prompt g

Cross section measured with 4% error

LUNA

^{14}N(p,g)^{15}O: σ down to 70 keV

ν_{cno} reduced by ~ 2 with 8% error → Sun core metallicity

Globular cluster age increased by 0.7-1 Gy

More carbon at the surface of AGB stars

^{15}N(p,g)^{16}O: σ down to 70 keV, reduced by ~ 2

^{25}Mg(p,g)^{26}Al: first measurement of the 92 keV resonance,

strength $\omega\gamma$=(2.9±0.6)x 10^{-10} eV

^{17}O(p,g)^{18}F: rate uncertainty @ Novae temperature reduced to 5%

→ uncertainty on ^{18}O, ^{18}F and ^{19}F less than 10% (from 40-50%)

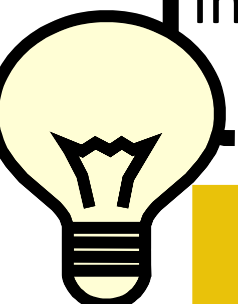
Future: Hydrogen and **Helium burning (3.5 MV**

LUNA MV

The Energy Scale from the "Observational" New Physics

- neutrino masses
- dark matter
- baryogenesis
- inflation

NO NEED FOR THE NP SCALE TO BE CLOSE TO THE ELW. SCALE

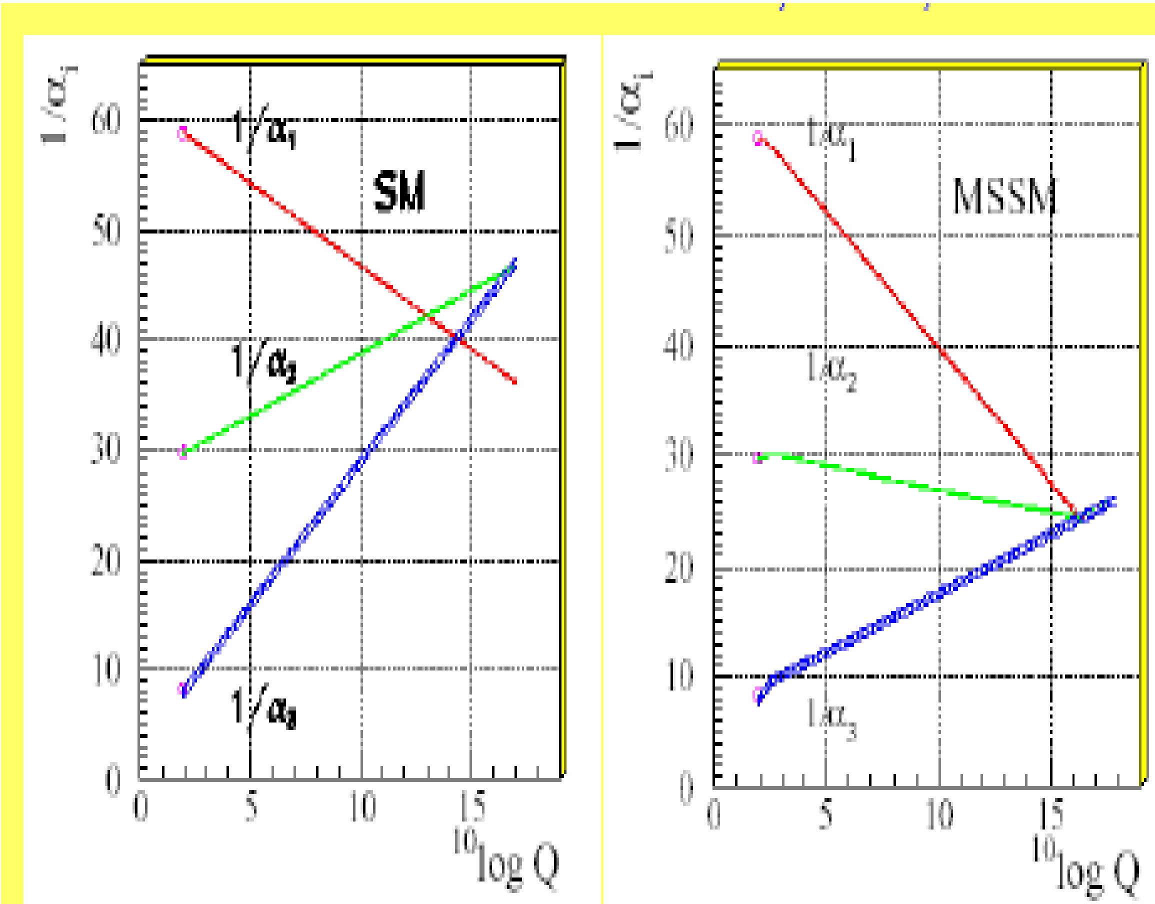


The Energy Scale from the "Theoretical" New Physics

★ ★ ★ **Stabilization of the electroweak symmetry breaking at M_W calls for an ULTRAVIOLET COMPLETION of the SM already at the TeV scale** **+**

★ **CORRECT GRAND UNIFICATION "CALLS" FOR NEW PARTICLES AT THE ELW. SCALE**

LOW-ENERGY SUSY AND UNIFICATION



Input

$$\alpha^{-1}(M_Z) = 128.978 \pm 0.027$$

$$\sin^2 \theta_{\overline{MS}} = 0.23146 \pm 0.00017$$

$$\alpha_s(M_Z) = 0.1184 \pm 0.0031$$

Output

$$M_{SUSY} = 10^{3.4 \pm 0.9 \pm 0.4}\ \text{GeV}$$

$$M_{GUT} = 10^{15.8 \pm 0.3 \pm 0.1}\ \text{GeV}$$

$$\alpha_{GUT}^{-1} = 26.3 \pm 1.9 \pm 1.0$$

THE COMPREHENSION OF THE ELECTROWEAK SCALE

$$V = \mu^2 |H|^2 + \lambda |H|^4$$ **μ ~ 10^2 GeV**

- M = O(10^{16} GeV)

	SU(3)	SU(2)	U(1)		SO(10)
L	1	2	-1/2		
e	1	1	1		
Q	3	2	1/6	→	16
u	3*	1	-2/3		
d	3*	1	1/3		

$$m_H^2 \sim -2\mu^2 + \frac{g^2}{(4\pi)^2} M^2$$

ONLY FOR SCALARS; SM FERMIONS AND GAUGE BOSON MASSES ARE PROTECTED BY THE SU(2) × U(1) SYMMETRY !

To comprehend (i.e. stabilize) the elw. scale need NEW PHYSICS (NP) to be operative at a scale $m_{NP} \ll M$

$$m_H^2 \sim -2\mu^2 + \frac{g^2}{(4\pi)^2} M^2$$

- **UNNATURAL or FINE-TUNING SOLUTION** tuning of parameters at the scale M with precision $O(m_H/M)^2$

- **NATURAL SOLUTION**
  Dynamics or symmetries or space-time modifications giving rise to a UV cut-off $\sim (m_H)^2$

- **SYMMETRY vs. MULTIVERSE**

The BIG and the SMALL- dim[m]

- $V = \mu^2|H|^2 + \lambda|H|^4$ what is the value of the energy of its vacuum, i.e. the SM **vacuum energy**?
  → $V_o = \mu^2 <H>^2 + \lambda <H>^4 \sim (100\ \text{GeV})^2$

observed vacuum energy, i.e. dark energy accelerating the expansion of the Universe O(10^{-3} eV)

- V defined up to a constant → choose such constant to **cancel** the O $(100\ \text{GeV})^2$ contribution
- **10^{-3} eV 10^{2} GeV 10^{16} GeV 10^{19} GeV**

- **Why** so different mass scales ?

- **How** to guarantee their separation → symmetry vs. multiverse

The BIG and the SMALL – dim[m]=0

- $h_t - h_e$ **flavour** issue
- L_{SM} no symmetry prevents to add a term violating **CP in the strong interactions** whose size depends on a **dimensionless** parameter θ → the bound on the neutron EDM → $\theta < 10^{-10}$
- **The θ – problem** : the symmetry solution

Axion from breaking of global chiral symmetry; axion field acts as dynamical theta para-meter, [Peccei,Quinn 77; Weinberg 78; Wilczek 78]

$$\mathcal{L} \supset -\frac{\alpha_s}{8\pi} \underbrace{\frac{A}{f_A}}_{\bar{\theta}} G^a_{\mu\nu} \tilde{G}^{a,\mu\nu}$$

spontaneously relaxing to zero, $\langle A \rangle = 0$ (thus CP conserved)

- mass due to chiral symmetry breaking $m_A \sim m_\pi f_\pi / f_A$
- has universal coupling to photons, $\mathcal{L} \supset -\frac{\alpha}{8\pi} C_0 \frac{A}{f_A} F_{\mu\nu} \tilde{F}^{\mu\nu}$

Ringwald

LOW-ENERGY SIGNATURES OF UNIFICATION AT 10^{16} GeV

- **PROTON DECAY** mediated by new particles (scalars or gauge bosons) related to the unified physics at 10^{16} GeV which DOES NOT respect the BARYON and LEPTON NUMBER SYMMETRIES → for a mediator of mass ~ 10^{16} GeV we expect a proton lifetime in the ballpark of ~ 10^{34} years → exp. accessible

- **NEUTRON-ANTINEUTRON OSCILLATION** if the unified symmetry (ex. SO(10)) breaks down to an intermediate symmetry subsequently spontaneously broken at ~ 10^6 GeV with the breaking of Baryon number of two units (ex. $SO(10) \rightarrow SU(4)_{PS} \times SU(2)_L \times SU(2)_R \rightarrow SU(3) \times SU(2)_L \times U(1)_Y$) → exp. accessible (for instance , at the ESS)

3 WAYS TO IMPLEMENT THE HIGGS MECHANISM

- **NO HIGGS PARTICLE**: **HIGGSLESS** MODEL (almost) killed by LHC (unlikely the observed scalar is an "impostor", however not impossible – ex. dilaton, radion. Possibility of mixing of an "authentic" Higgs with the "impostor"…)

- **COMPOSITE HIGGS**: PSEUDO-GOLDSTONE BOSON

- **ELEMENTARY HIGGS**

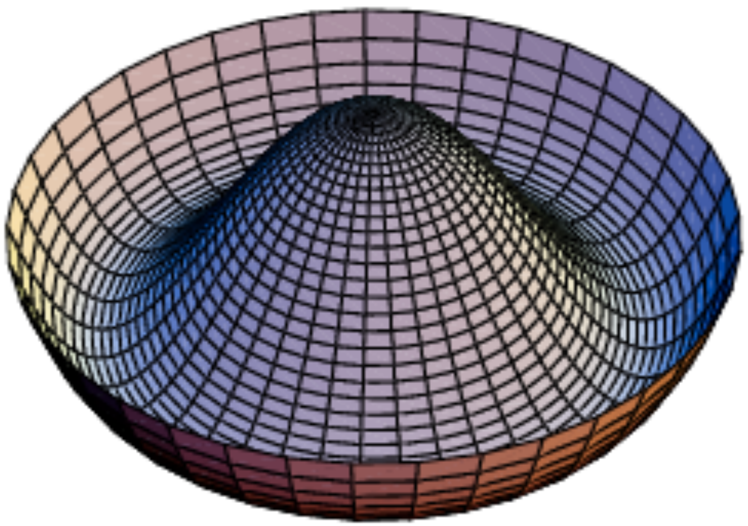
A) FINE-TUNED (unnatural Higgs – anthropic road, high-scale fundamental theory taking care of it, …)

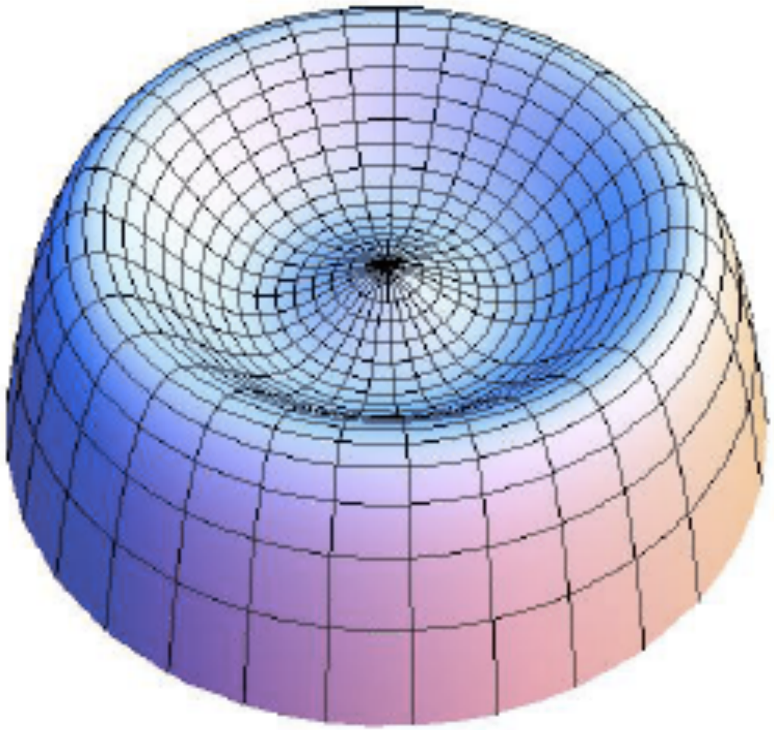
B) NATURAL (protection mechanism: low-energy SUSY; inexistence of the scale hierarchy problem: extra dimensions, warped space, …)

On the peculiar value of M_H

- **For the SM to survive up to a very large scale, M_{GUT} or M_{Planck} : M_H in the fork 125 – 180 GeV, with ~ 125 GeV just on the verge between stability and instability of the vacuum state where the SM sits**
- For the existence of a **(minimal) supersymmetric extension of the SM** at the elw. scale, the lightest SUSY Higgs must have **$M_h < 130$ GeV** (for $M_h > 120$ GeV, the radiative correction to M_h is ~ 50% of the tree-level value)

STABILITY ⟷ **INSTABILITY**





ON THE IMPORTANCE OF PRECISELY MEASURING HIGGS and TOP MASSES

to know to the last digit

- The perfect machine for COUPLINGS is TLEP

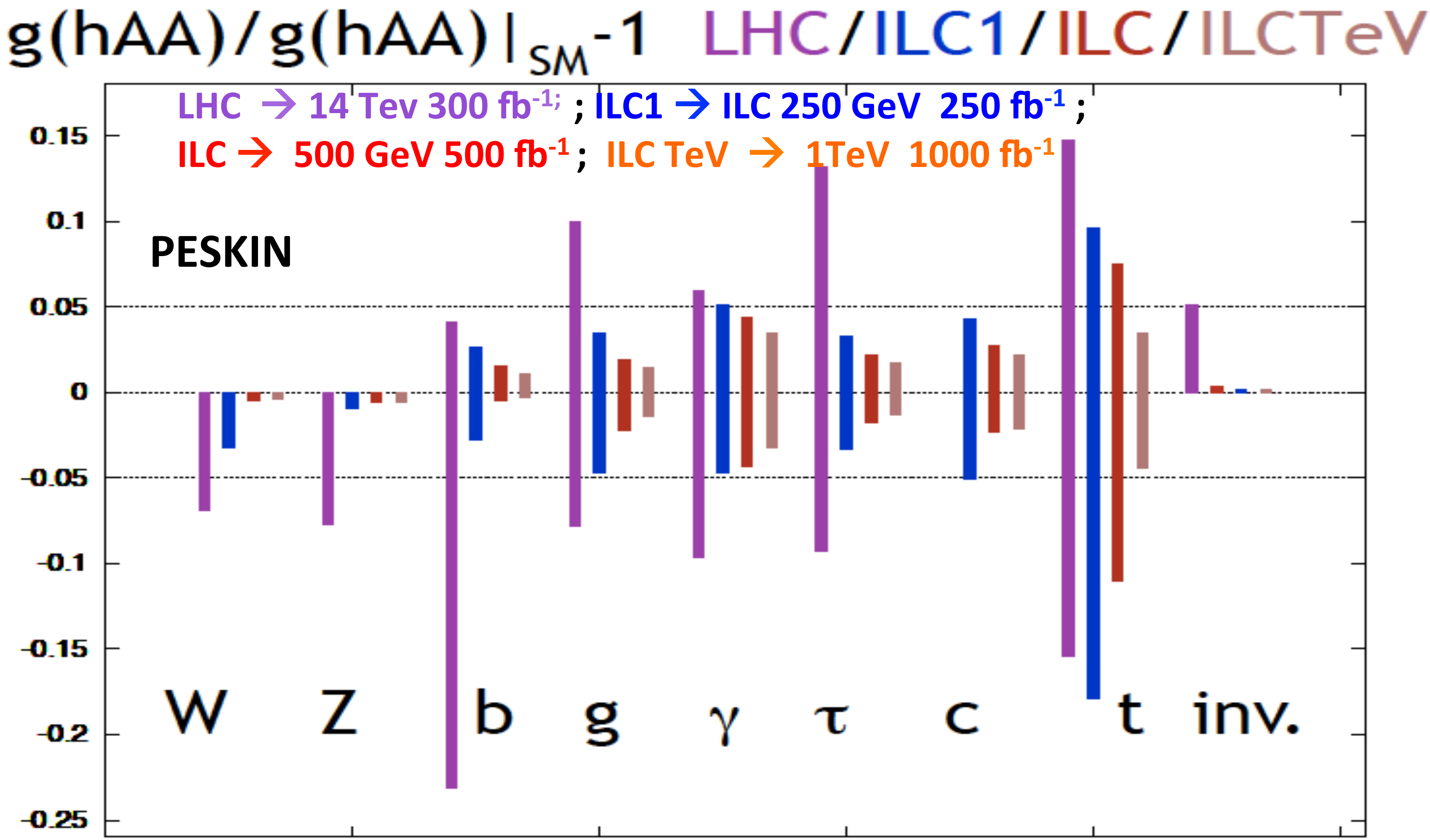
Very large FCC (Future Circular Collider) of 70-100 Km.
1st phase with e^+-e^- ; 2nd phase with p-p at 100 TeV

- The optimal machine for H-coupling, t-quark mass, HHH is ILC

- The unique machine for H total width is a muon factory

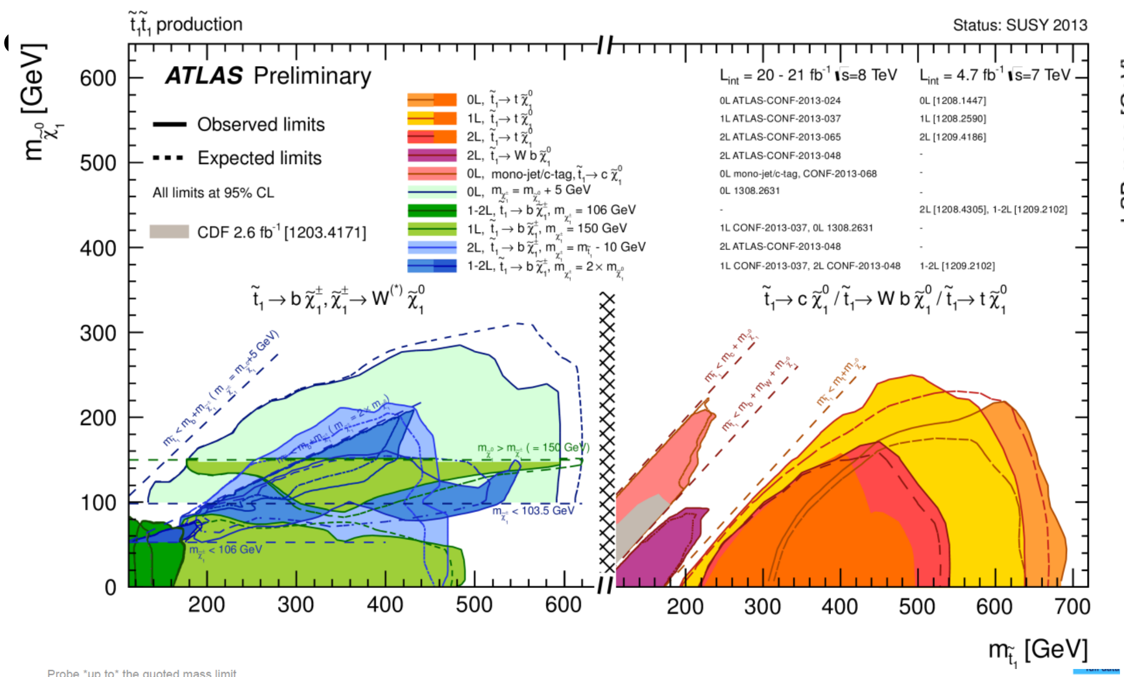
F. Ferroni Varenna 2013

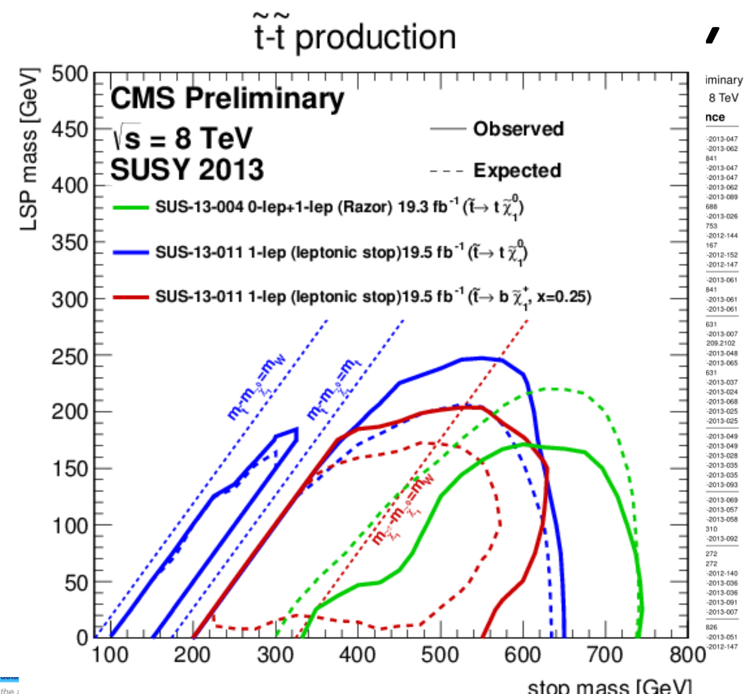
HIGGS Couplings Sensitivity at LHC and ILC



SUSY searches

- Higgs mass value reduces SUSY parameter space
- Direct searches unsuccessful → gluinos well above 1 TeV
- Working on stop expected lighter





HIGH ⟷ LOW ENERGY HADRONIC PHYSICS

- Still **open problems** in low-energy hadronic physics → possible links with new physics beyond the SM searched for in high-energy hadronic physics ?

- Ex: the **PROTON CHARGE RADIUS PUZZLE**

  → new light, very weakly coupled scalar particle

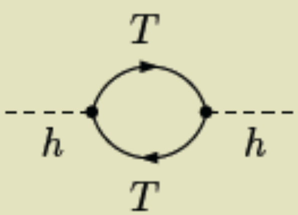
Probing New Physics with Underground Accelerators and Radioactive Sources Pospelov et al arXiv:1405.4864 [hep-ph] → possible exps. with LUNAMV or SOX and Borexino

Higgs and flavor physics as indirect BSM probes

NEUBERT SUSY2012

$$\mathcal{L}_{\rm EFT} = \Lambda_{\rm UV}^2\,\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\rm UV}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\rm UV}^2} + \dots$$

electroweak symmetry breaking $\Downarrow$ Higgs mass

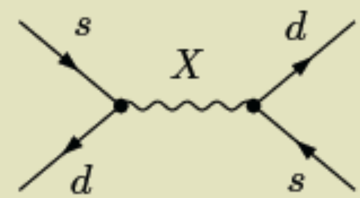


$$\sim \frac{g_T^2}{16\pi^2}\Lambda_{\rm UV}^2$$

no fine-tuning $\Downarrow$

$$\Lambda_{\rm Higgs} \lesssim 1\ \text{TeV}$$

$\Downarrow$



$$\sim \frac{g_X^2}{\Lambda_{\rm UV}^2}$$

bounds on flavor mixing $\Downarrow$ assuming *generic* flavor structure

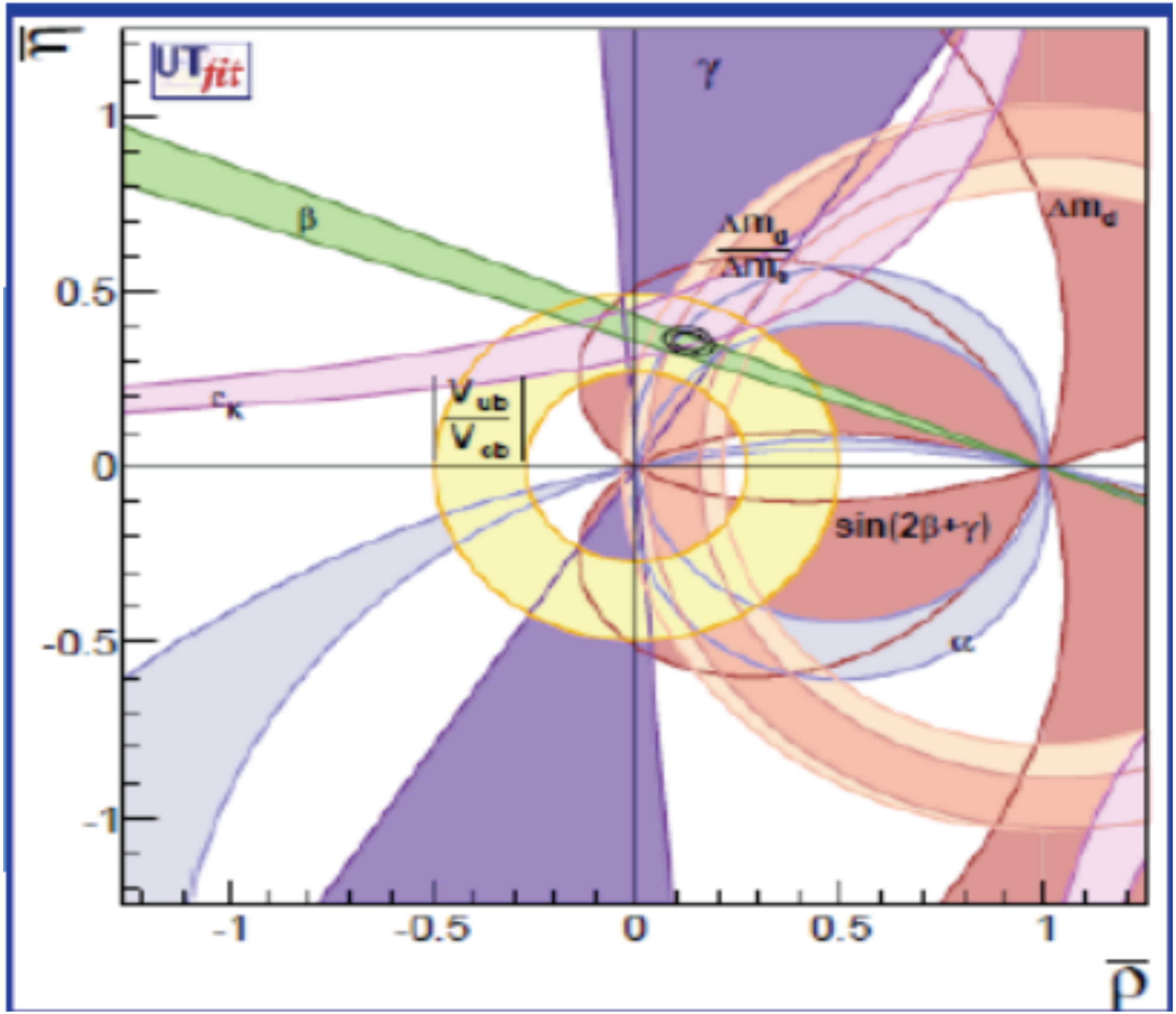
$$\Lambda_{\rm flavor} \gtrsim 10^3\ \text{TeV}$$

Possible solutions to flavor problem explaining $\Lambda_{\rm Higgs} << \Lambda_{\rm flavor}$:

(i) $\Lambda_{\rm UV} >> 1$ TeV: **Higgs fine tuned**, new particles too heavy for LHC

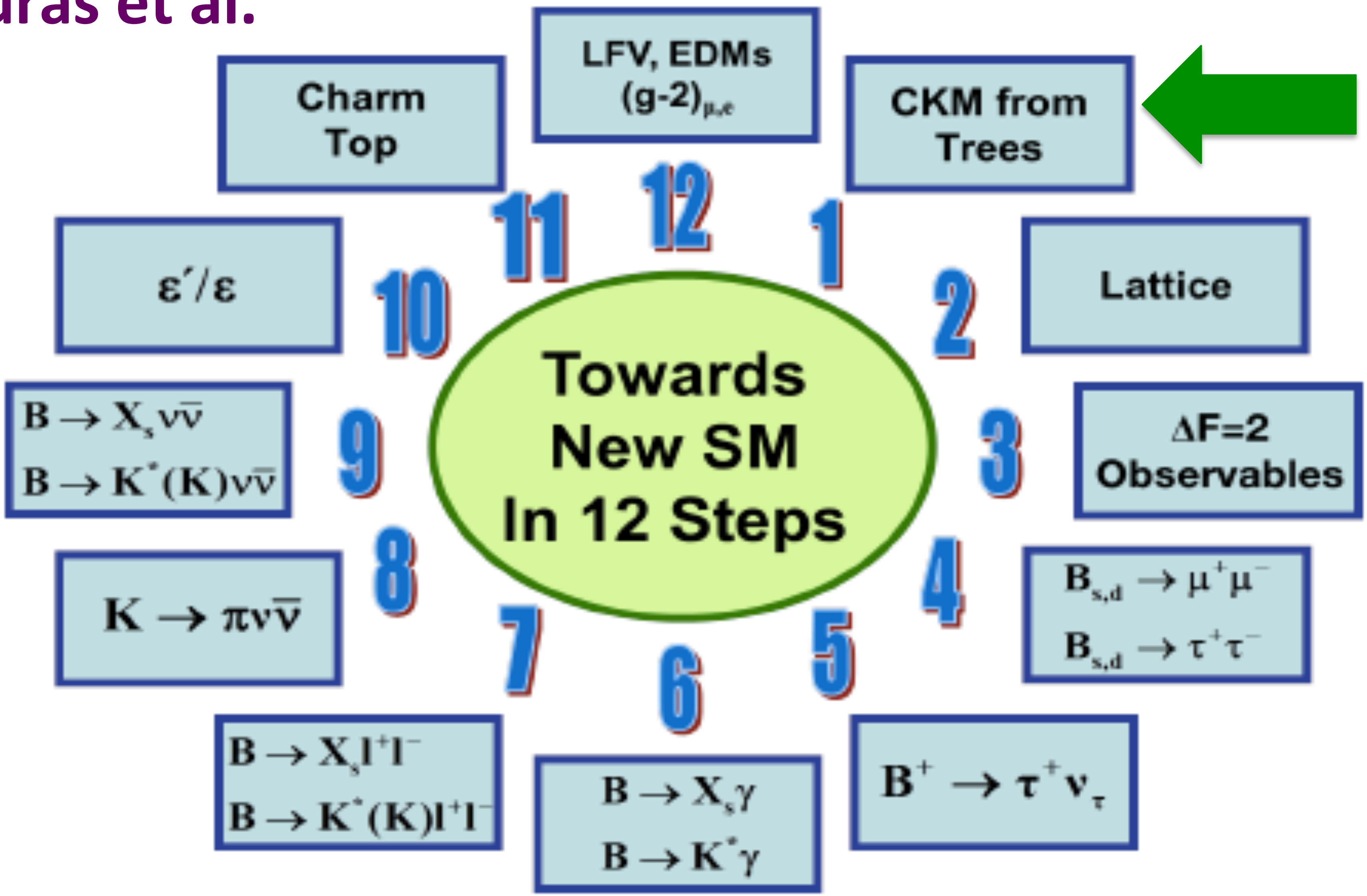
(ii) $\Lambda_{\rm UV} \approx 1$ TeV: quark flavor-mixing protected by a **flavor symmetry**

the (almost complete) CKM triumph



L' orologio del flavor deve proseguire

Buras et al.



THE FATE OF LEPTON NUMBER

L VIOLATED → υ Majorana ferm.

L CONSERVED → υ Dirac ferm. (dull option)

$h\,\bar{\upsilon}_L H\,\upsilon_R \rightarrow m_\upsilon = h\,\langle H\rangle$ $\quad M_\upsilon < 5$ eV $\rightarrow h < 10^{-11}$

EXTRA-DIM. ν_R in the bulk: small overlap?

SMALLNESS of m_υ

↓

PRESENCE OF A NEW PHYSICAL MASS SCALE

NEW HIGH SCALE / NEW LOW SCALE

NEW HIGH SCALE: SEE - SAW MECHAN.

Minkowski; Gell-Mann, Ramond, SlansKy, Vanagida

↓

ν_R ENLARGEMENT OF THE FERMIONIC SPECTRUM

$M\upsilon_R\upsilon_R + h\,\bar{\upsilon}_L\,\phi\,\upsilon_R$

	υ_L	υ_R
υ_L	$\sim O$	$h\,\langle\phi\rangle$
υ_R	$h\,\langle\phi\rangle$	M

LR Models?

NEW LOW SCALE: MAJORON MODELS

Gelmini, Roncadelli

↓

Δ ENLARGEMENT OF THE HIGGS SCALAR SECTOR

$h\,\upsilon_L\upsilon_L\,\Delta$

$m_\upsilon = h\,\langle\Delta\rangle$

N.B.: EXCLUDED BY LEP!

Going beyond the SM:
the NEUTRINO MASS

A. GIULIANI, SAC APPEC 2013

Cosmology, **single** and **double β decay** measure different combinations of the neutrino mass eigenvalues, constraining the **neutrino mass scale**

In a standard three active neutrino scenario:

$$\Sigma \equiv \sum_{i=1}^{3} M_i$$

cosmology
simple sum
pure kinematical effect

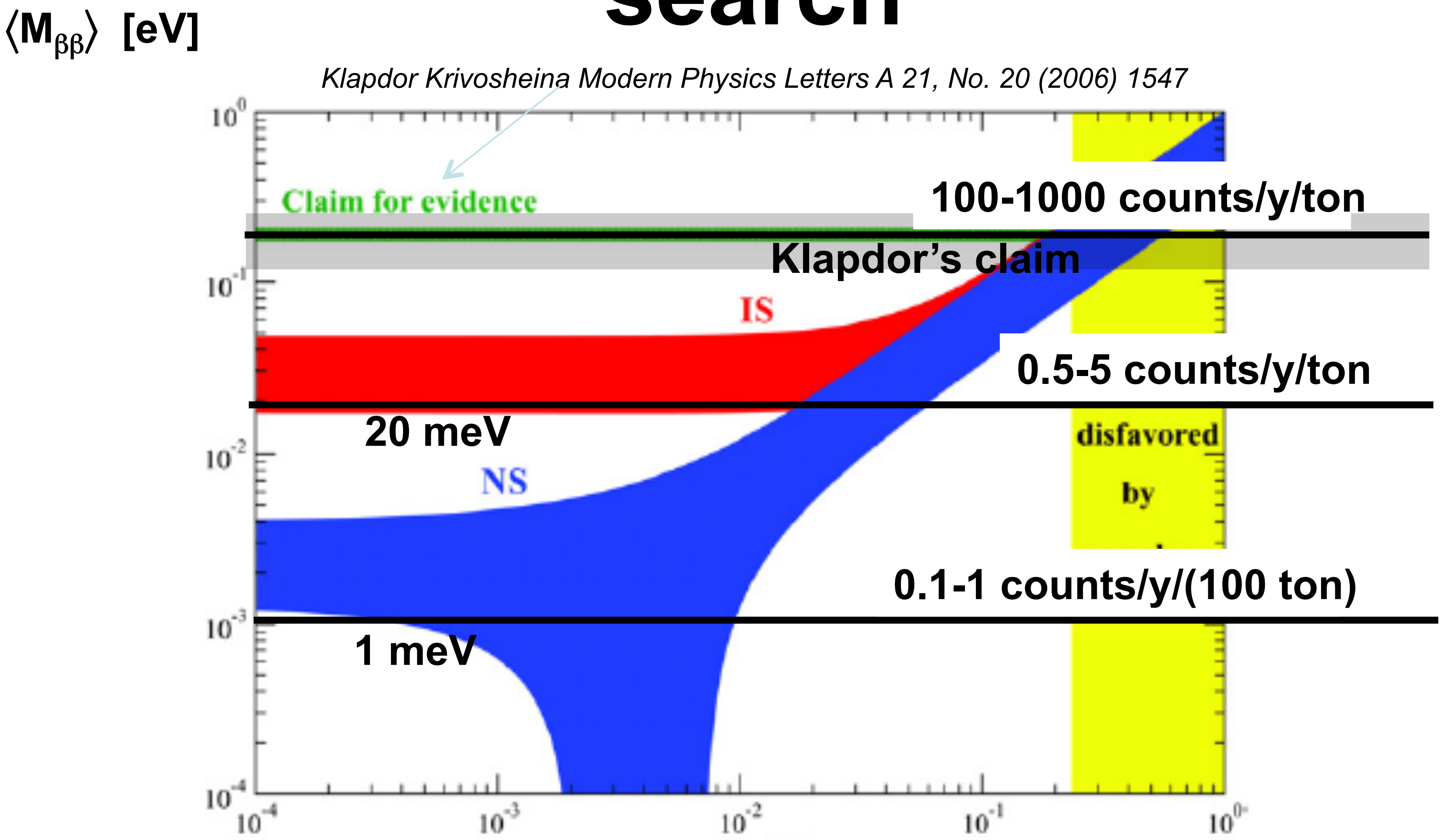
$$\langle M_\beta \rangle \equiv \left(\sum_{i=1}^{3} M_i^2 \, |U_{ei}|^2 \right)^{1/2}$$

β decay
incoherent sum
real neutrino

$$\langle M_{\beta\beta} \rangle \equiv \left| \sum_{i=1}^{3} M_i \, |U_{ei}|^2 \, e^{i\alpha_i} \right|$$

double β decay
coherent sum
virtual neutrino
Majorana phases

Three challenges for 0ν-DBD search



The next step

It is clear that at least **1 ton isotope** is required to explore the inverted hierarchy region

- Impact of enrichement cost

Isotope	Abundance	Price/kg [k$]	Price/(10 t) [M$]
^{76}Ge	7.61	~ 80	800 (640)*)
^{82}Se	8.73	~ 120	1200 (1000)*)
^{100}Mo	9.63	~ 80	800 (640)*)
^{116}Cd	7.49	~ 180	1800 (1440)*)
^{130}Te	34.08	~ 20	200 (160)*)
^{136}Xe	8.87	~ 5-10	50-100 (40-80)*)
^{150}Nd (?)	5.6	> 200	> 2000

Barabash, 2013

- How many technological approaches and which ones?

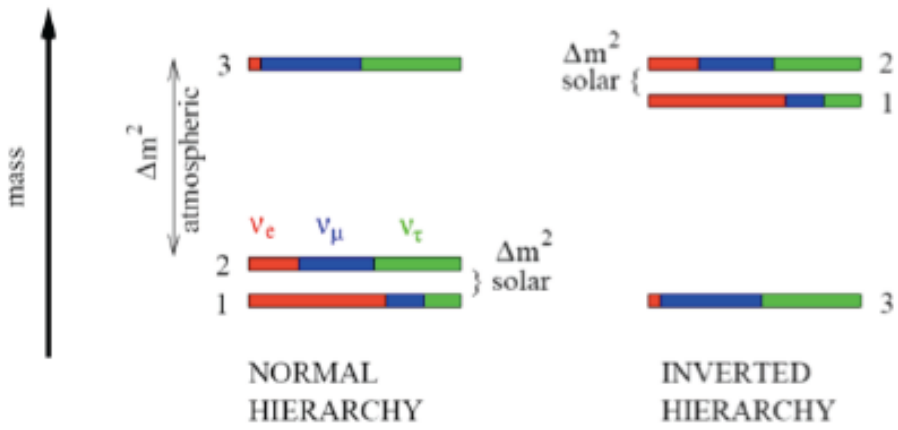
- How many isotopes and which ones?

- **Which infrastructures?**
  Which chance do we have to get them in Europe?

A. Giuliani SAC APPEC 2013

Neutrino oscillations & sterile neutrinos

- **Atmospheric neutrinos(θ_{23})**
  - SuperK，HyperK/UNO，INO，TITAND,...
- **Solar neutrinos(θ_{12}):**
  - GALLEX/SAGE, SuperK, SNO, Borexino, XMASS, ...
- **Reactor neutrinos(θ_{12},θ_{13} → mass hierarchy):**
  – KamLAND, Daya Bay→ JUNO, Double CHOOZ, Reno,...
- **Accelerator neutrinos(θ_{23},θ_{13} → mass hierarchy, δ, ...):**
  – MINOS, OPERA, MiniBooNe, T2K, NOVA, ICARUS...



CPV

+ A number of anomalies:

LSND ?

Reactor neutrino flux ?

Sterile neutrinos ? MiniBoone

MATTER-ANTIMATTER ASYMMETRY ⟷ NEUTRINO MASSES CONNECTION: BARYOGENESIS THROUGH LEPTOGENESIS

- Key-ingredient of the SEE-SAW mechanism for neutrino masses: **large Majorana mass for RIGHT-HANDED neutrino**
- In the early Universe the heavy RH neutrino decays with Lepton Number violatiion; if these decays are accompanied by a new source of CP violation in the leptonic sector, then

→ it is possible to create a lepton-antilepton asymmetry at the moment RH neutrinos decay. Since SM interactions preserve Baryon and Lepton numbers at all orders in perturbation theory, but violate them at the quantum level, such **LEPTON ASYMMETRY** can be converted by these purely quantum effects into a BARYON-ANTIBARYON ASYMMETRY (**Fukugita-Yanagida mechanism for leptogenesis**)

LFV IN SUSY SEE-SAW

SEE- SAW (type 1)

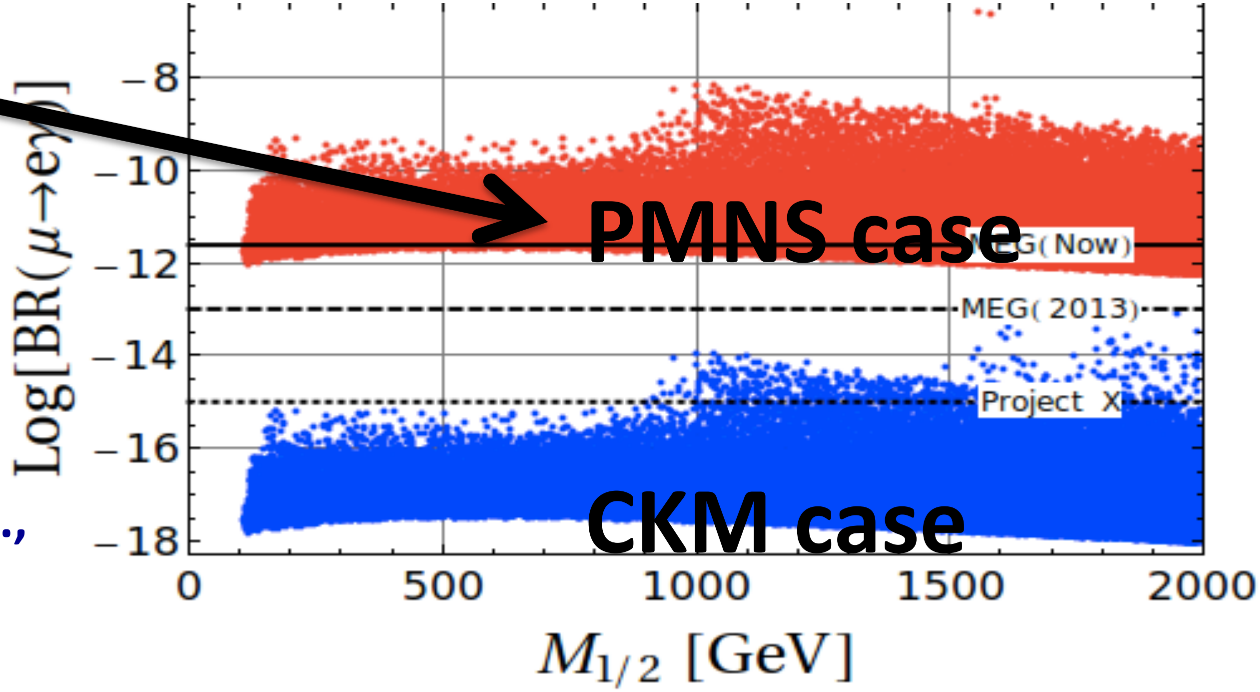
New source of (leptonic) flavor:

YUKAWA COUPLINGS OF THE NEUTRINO DIRAC MASS CONTRIBUTIONS, i.e. **THE YUKAWAs** of the **HIGGS couplings to the LETF- and RIGHT – HANDED NEUTRINOS**

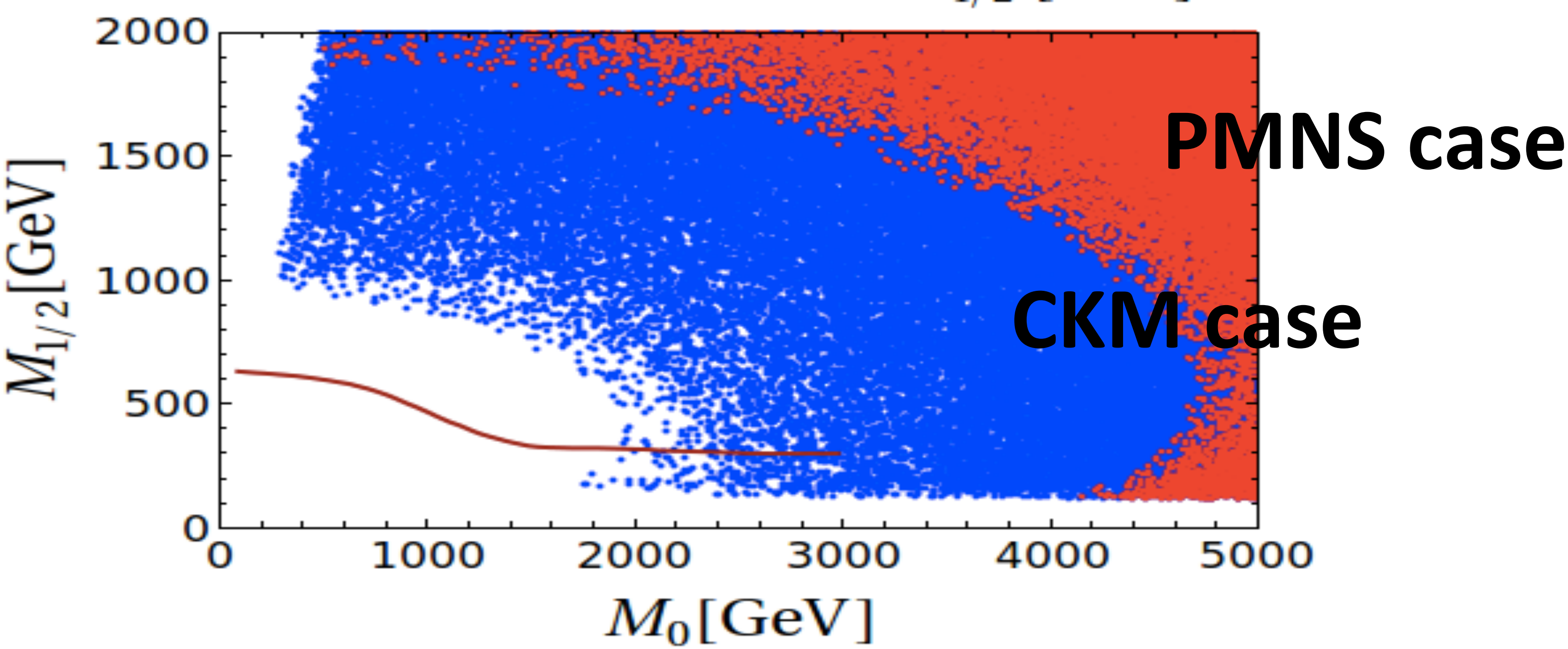
LOW-ENERGY SUSY

The scalar lepton masses through their running bring memory of those new sources of leptonic flavor at the TeV scale, i.e. at energies much below the (Majorana) mass of the RH neutrinos

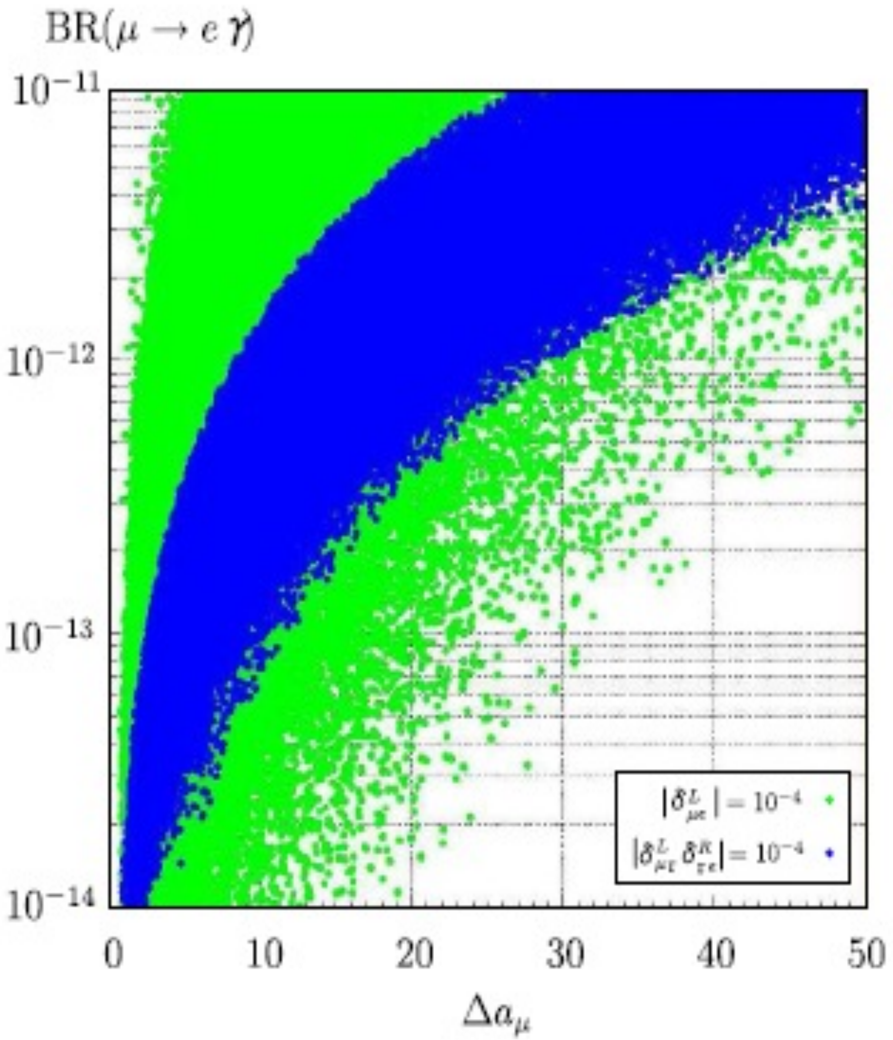
PMNS case in mSUGRA with tanβ = 10

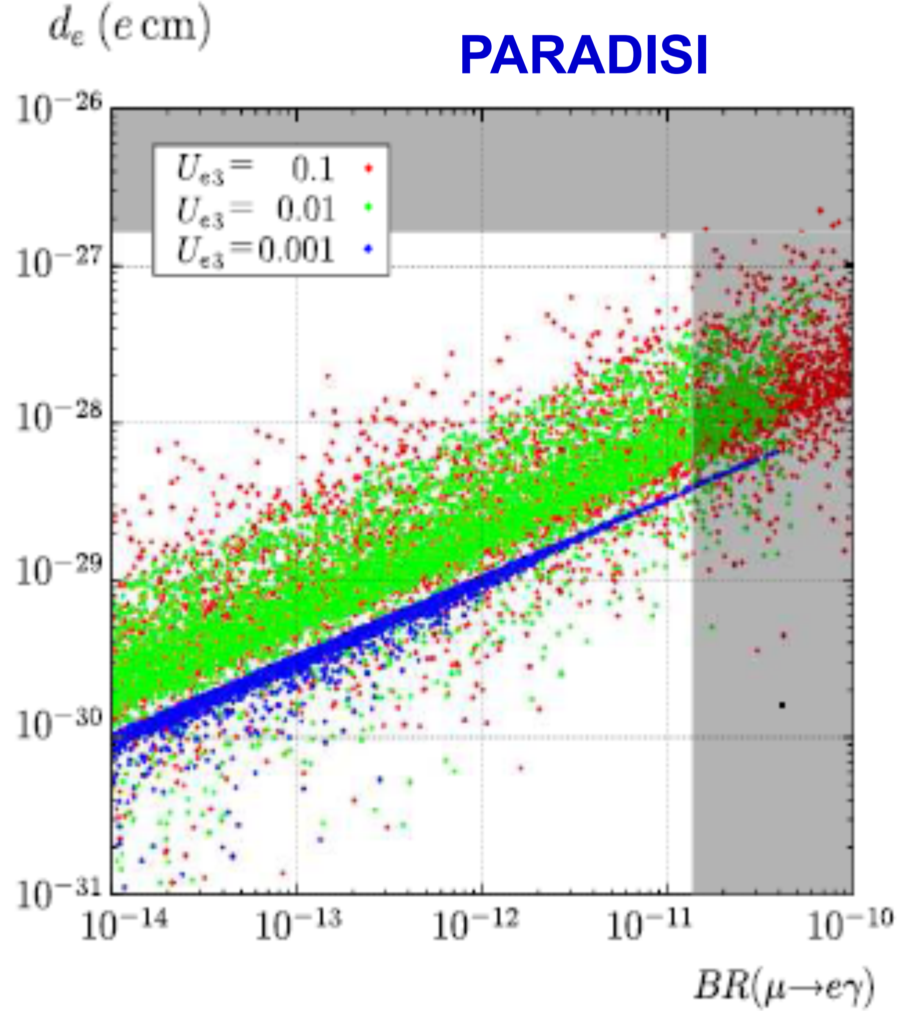


Calibbi, Chowdhuri, A. M., Patel, Vempati 2012

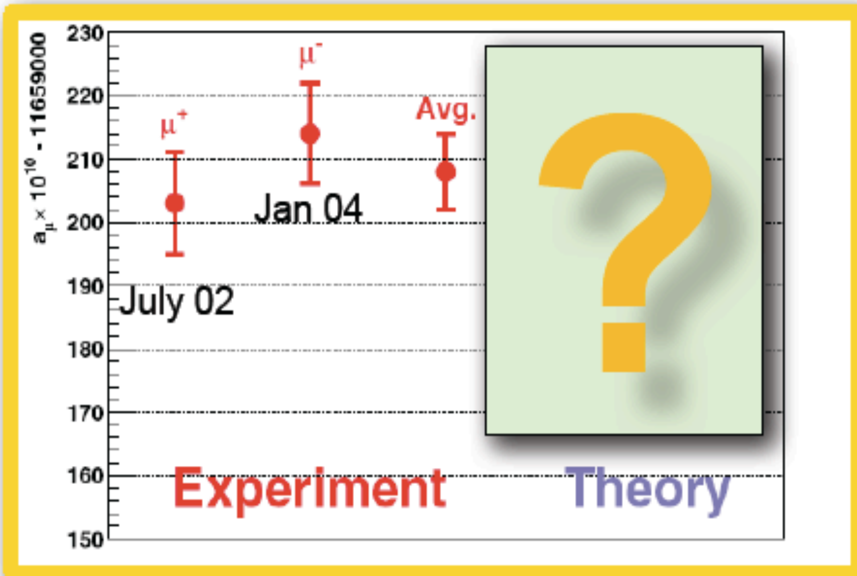


LFV, g – 2, EDM: a promising correlation in SUSY SEESAW





The muon g-2: the experimental result



- **Today:** $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys})\times 10^{-11}$ [0.5ppm].
- **Future:** new muon g-2 experiments proposed at:
  - Fermilab E989, aiming at $\pm 16\times 10^{-11}$, ie 0.14ppm
  - J-PARC aiming at 0.1 ppm

  See B. Lee Roberts & T. Mibe @ Tau2012, September 2012

Sep 2012:
CD0 approval!
Data in (late)
2016?

- Are theorists ready for this (amazing) precision? No(t yet)

The muon g-2: SM vs. Experiment

Adding up all contributions, we get the following SM predictions and comparisons with the measured value:

$a_\mu^{EXP} = 116592089\ (63) \times 10^{-11}$

E821 – Final Report: PRD73 (2006) 072 with latest value of $\lambda = \mu_\mu/\mu_p$ from CODATA'06

$a_\mu^{SM} \times 10^{11}$	$\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}$	σ
116 591 794 (66)	$295\ (91) \times 10^{-11}$	3.2 [1]
116 591 814 (57)	$275\ (85) \times 10^{-11}$	3.2 [2]
116 591 840 (58)	$249\ (86) \times 10^{-11}$	2.9 [3]

with the "conservative" $a_\mu^{HHO}(lbl) = 116\ (39) \times 10^{-11}$ and the LO hadronic from:

[1] Jegerlehner & Nyffeler, Phys. Rept. 477 (2009) 1
[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar & KLOE10 2π)
[3] Hagiwara et al, JPG38 (2011) 085003 (includes BaBar & KLOE10 2π)

Note that the th. error is now about the same as the exp. one

THE EDM CHALLENGE

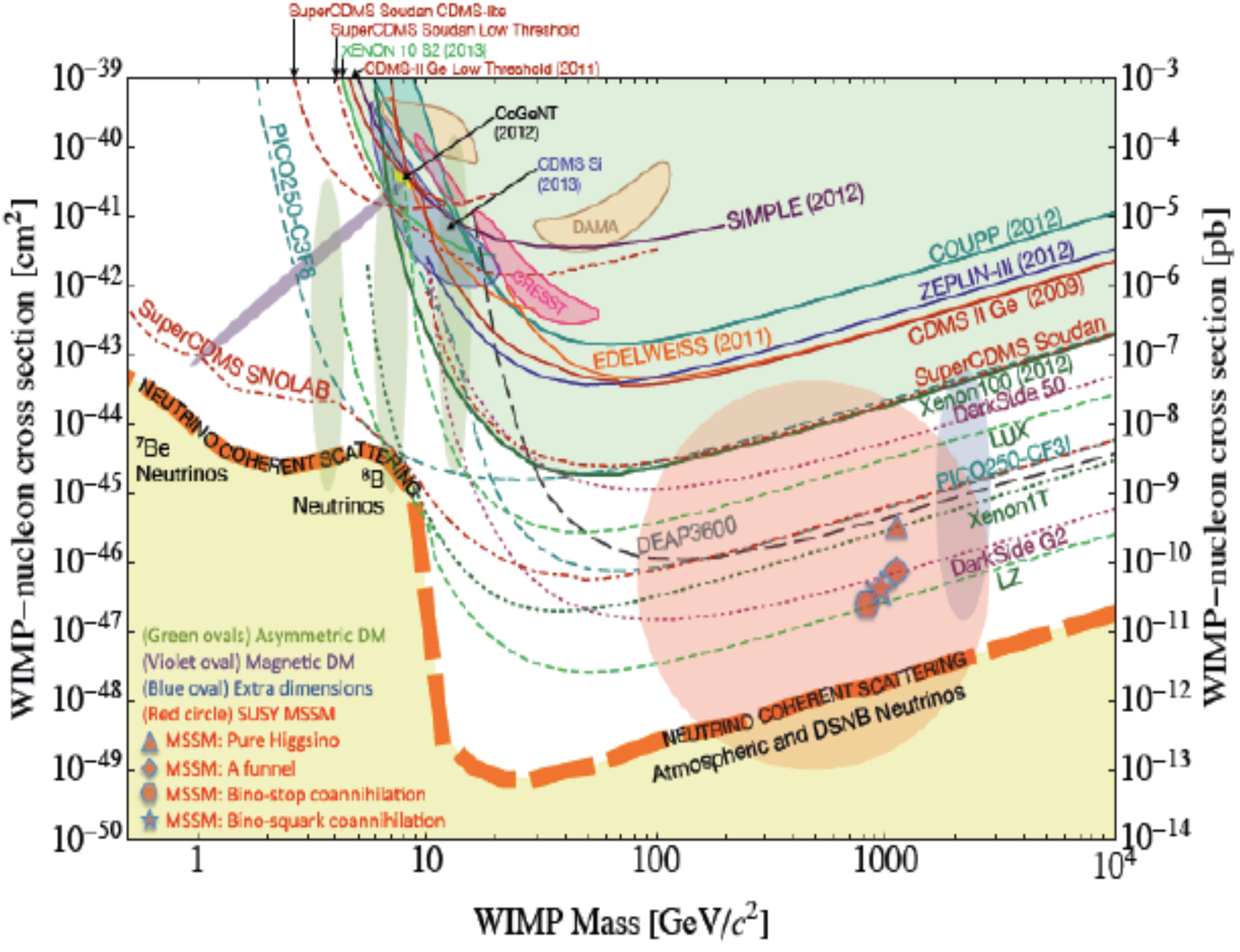
FOR **ANY** **NEW PHYSICS AT THE TEV SCALE** WITH **NEW SOURCES OF CP VIOLATION** → NEED FOR **FINE-TUNING** TO PASS THE EDM TESTS OR SOME **DYNAMICS TO SUPPRESS THE CPV** IN FLAVOR CONSERVING EDMS

$$|d_{\rm n}| < 2.9 \times 10^{-26} e \text{ cm } (90\%\text{C.L.}),$$
$$|d_{\rm Tl}| < 9.0 \times 10^{-25} e \text{ cm } (90\%\text{C.L.}),$$
$$|d_{\rm Hg}| < 3.1 \times 10^{-29} e \text{ cm } (95\%\text{C.L.}).$$

CONNECTION DM – ELW. SCALE

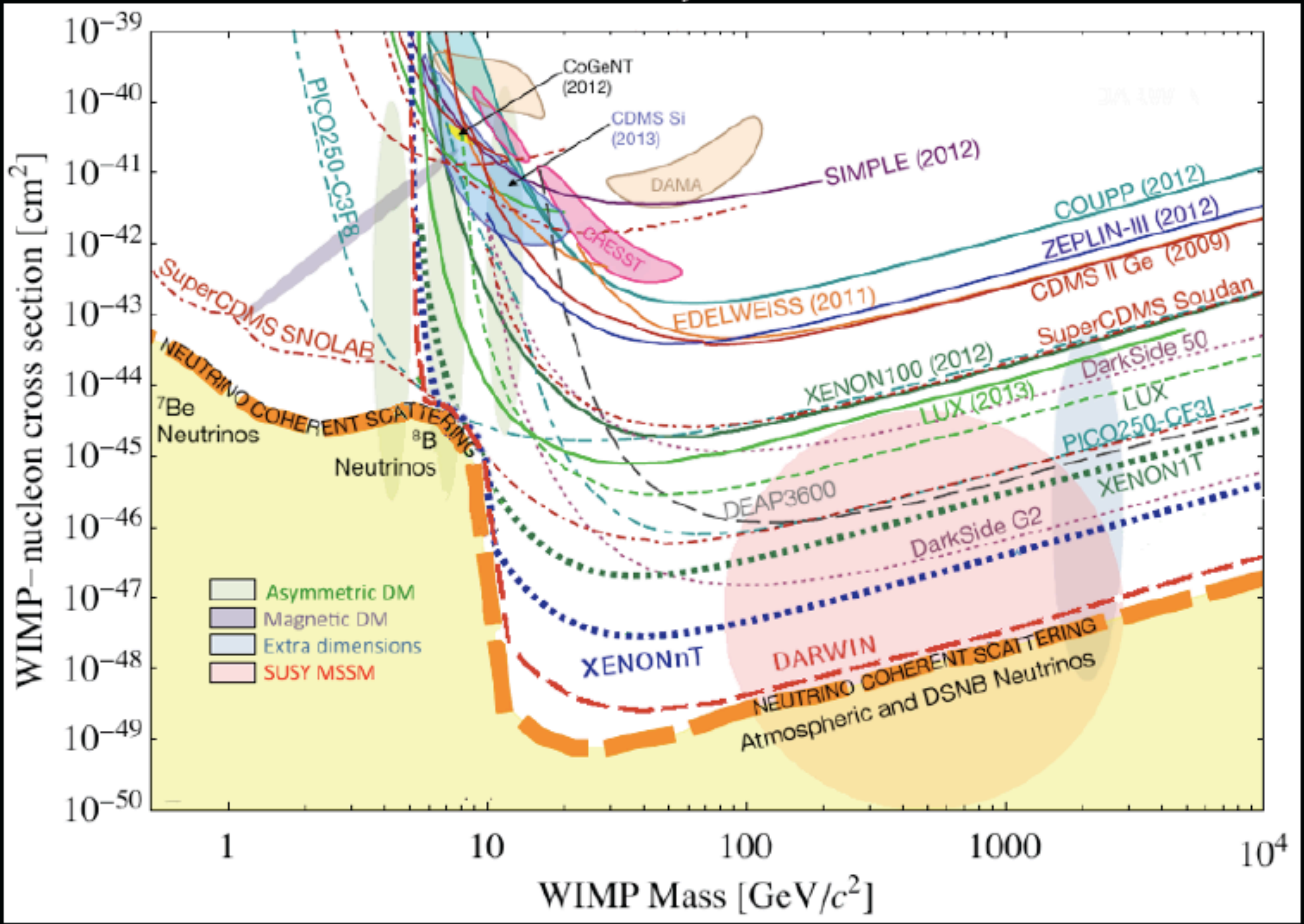
THE WIMP MIRACLE :STABLE ELW. SCALE WIMPs

	SUSY	EXTRA DIM.	LITTLE HIGGS.
1) **ENLARGEMENT OF THE SM**	(x^{μ}, θ) Anticomm. Coord.	(x^{μ}, j^{i}) New bosonic Coord.	SM part + new part to cancel Λ^2 at 1-Loop
2) **SELECTION RULE**	***R-PARITY LSP***	***KK-PARITY LKP***	***T-PARITY LTP***
→ **DISCRETE SYMM.** → **STABLE NEW PART.**	Neutralino spin 1/2	spin1	spin0
3) FIND REGION (S) PARAM. SPACE WHERE THE "L" NEW PART. IS NEUTRAL + $\Omega_L h^2$ OK	↓ m_{LSP} ~100 - 200 GeV	↓ m_{LKP} ~600 - 800 GeV	↓ m_{LTP} ~400 - 800 GeV



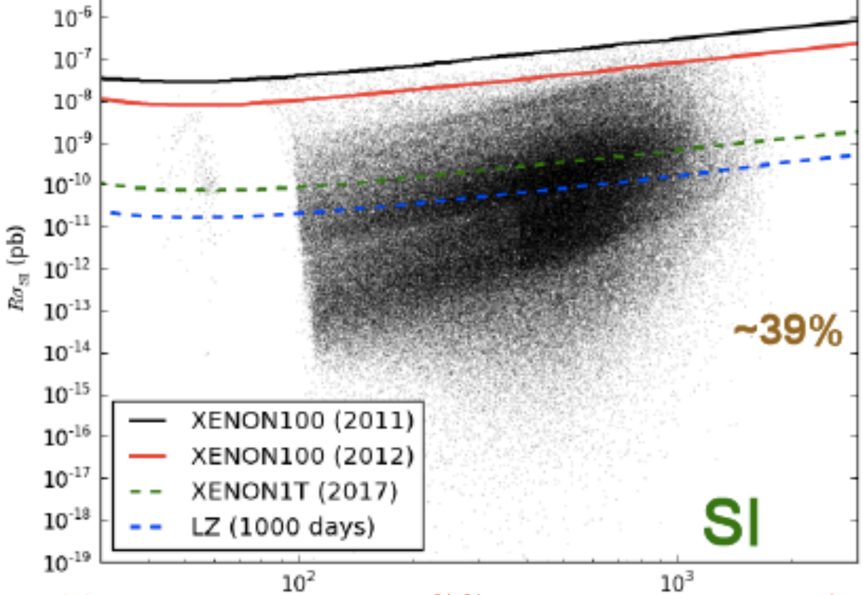
SuperCDMS Soudan CDMS-lite
SuperCDMS Soudan Low Threshold
XENON 10 S2 (2013)
CDMS-II Ge Low Threshold (2011)
CoGeNT (2012)
CDMS Si (2013)
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
CRESST
EDELWEISS (2011)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
PICO250-C3F8
Xenon1T
DarkSide G2
LZ
DEAP3600
SuperCDMS SNOLAB
NEUTRINO COHERENT SCATTERING
7Be Neutrinos
8B Neutrinos
Atmospheric and DSNB Neutrinos
(Green ovals) Asymmetric DM
(Violet oval) Magnetic DM
(Blue oval) Extra dimensions
(Red circle) SUSY MSSM
MSSM: Pure Higgsino
MSSM: A funnel
MSSM: Bino-stop coannihilation
MSSM: Bino-squark coannihilation
WIMP–nucleon cross section [cm2]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c2]

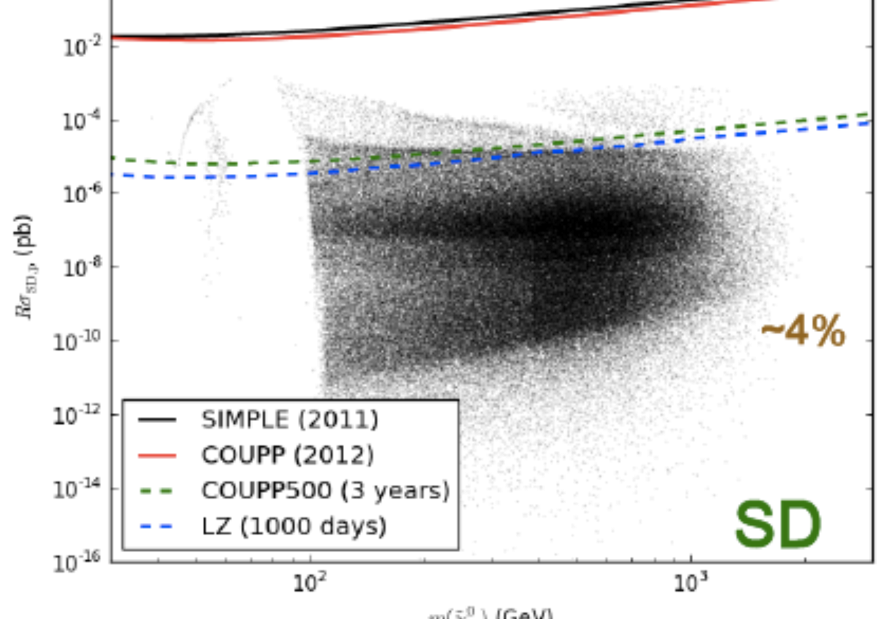
1) Science Goals: Dark Matter Projected Sensitivities



What if 2+ of these experiments observe strong candidate dark matter signals?

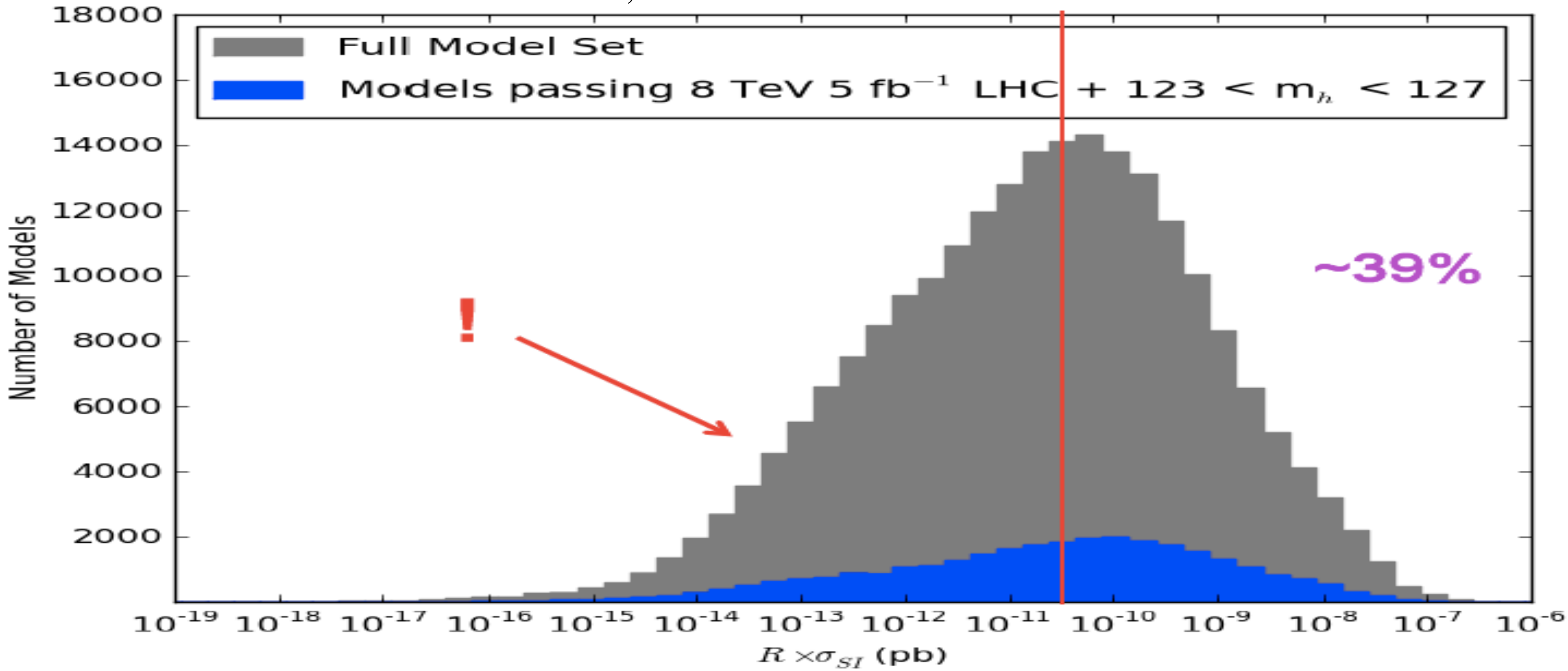
Build a directional detector to establish astrophysical origin.



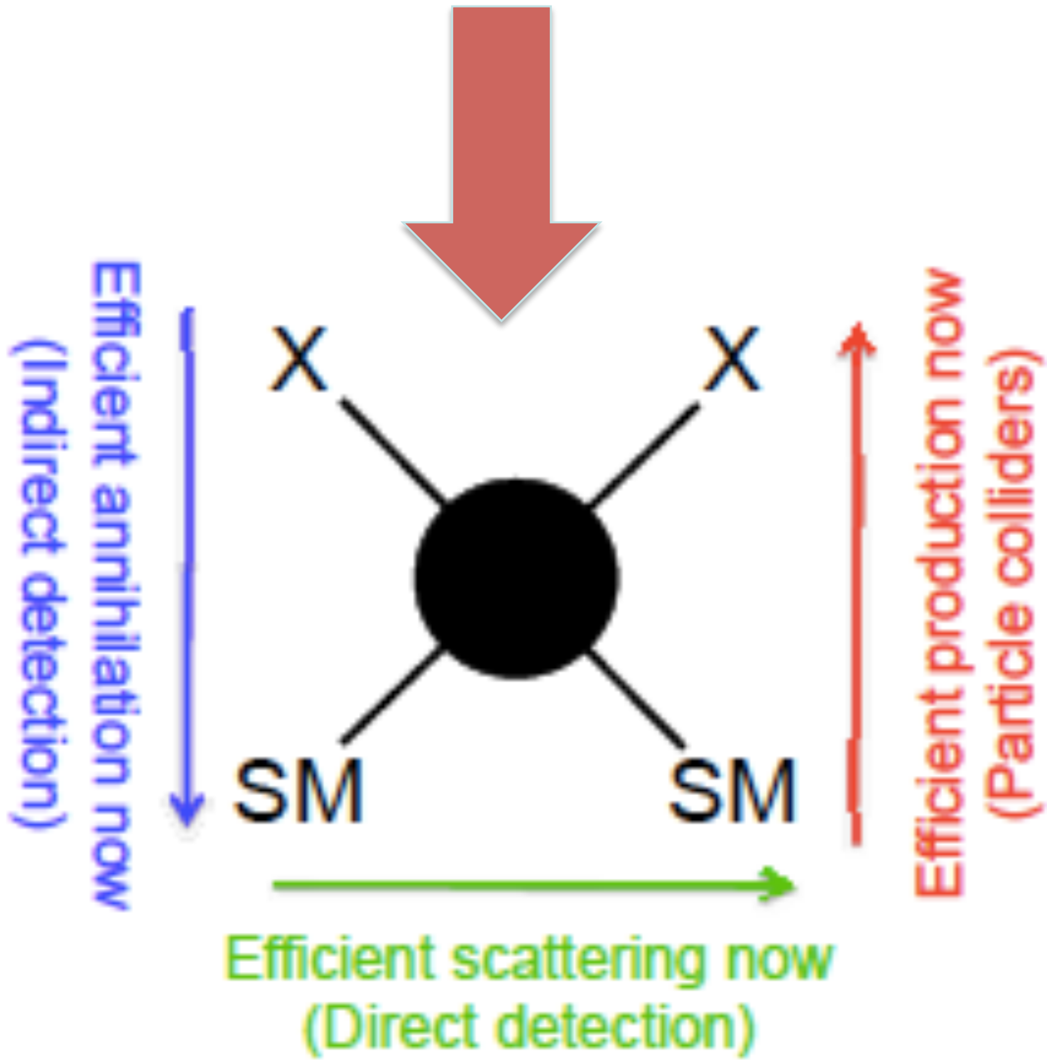


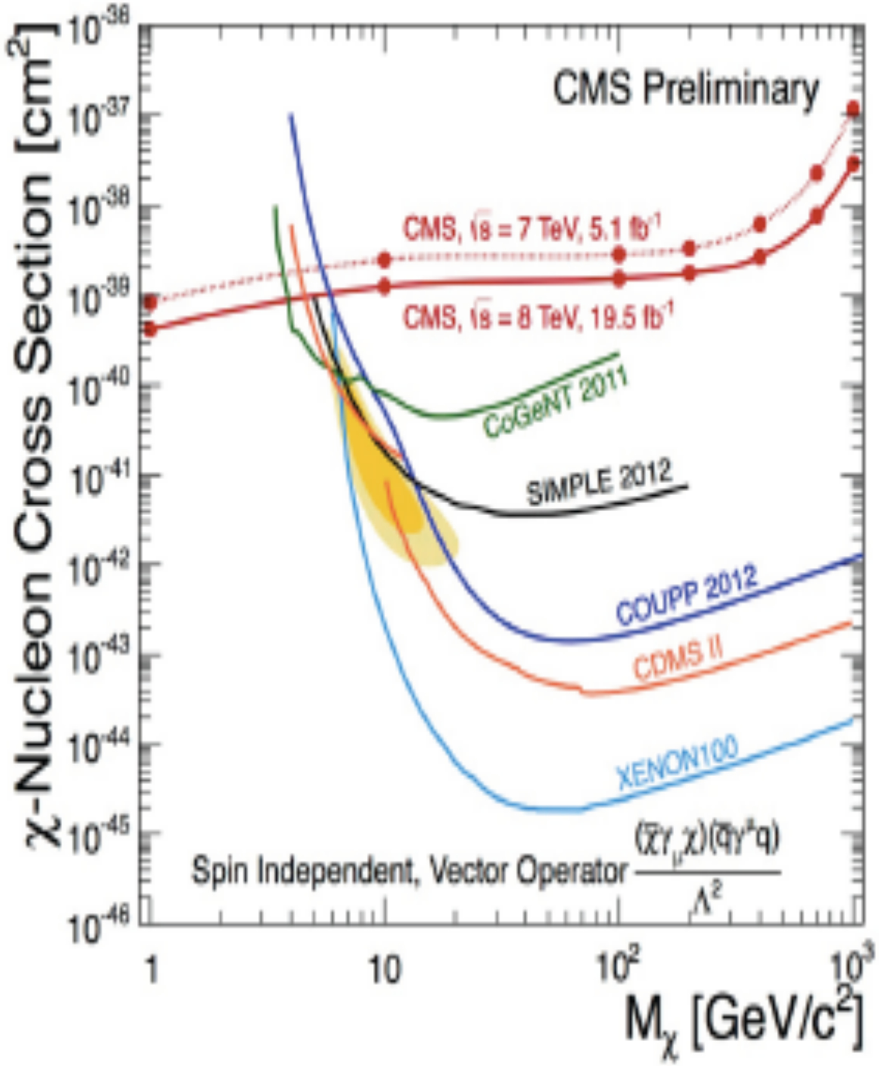
125k models pMSSM under scrutiny

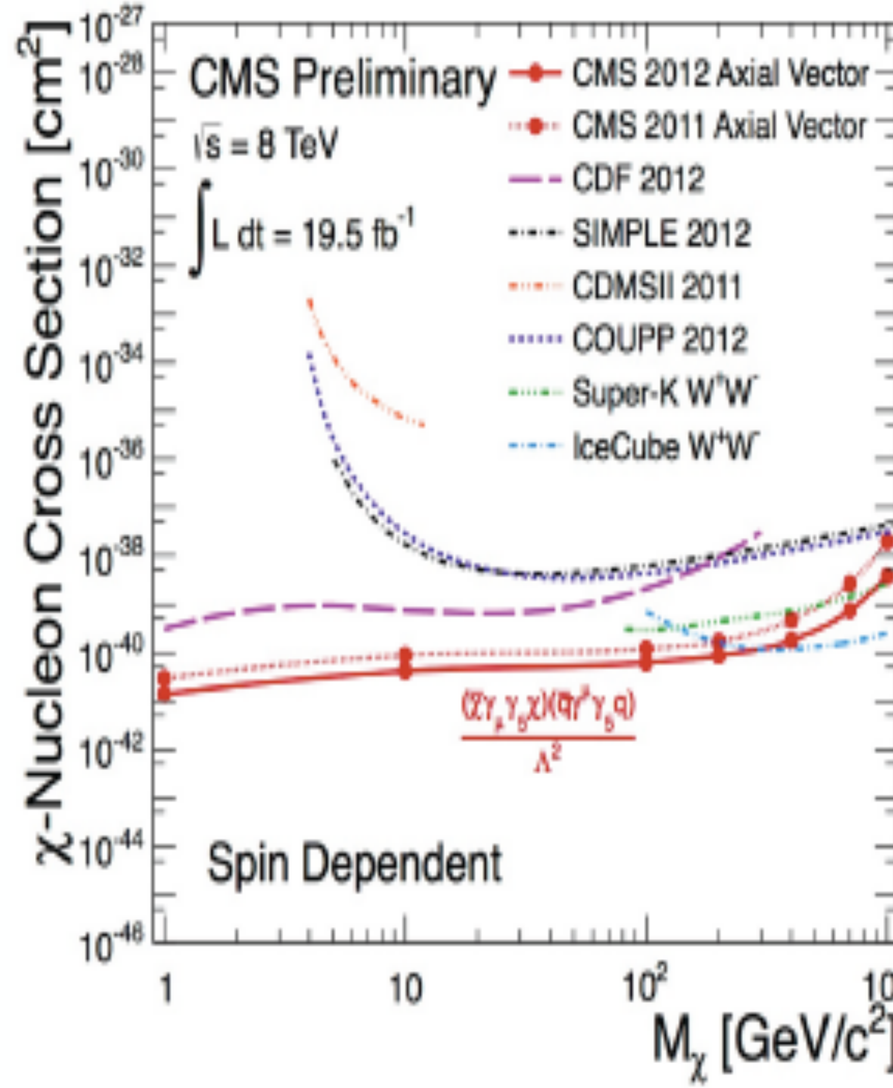
Hewett, Rizzo et al



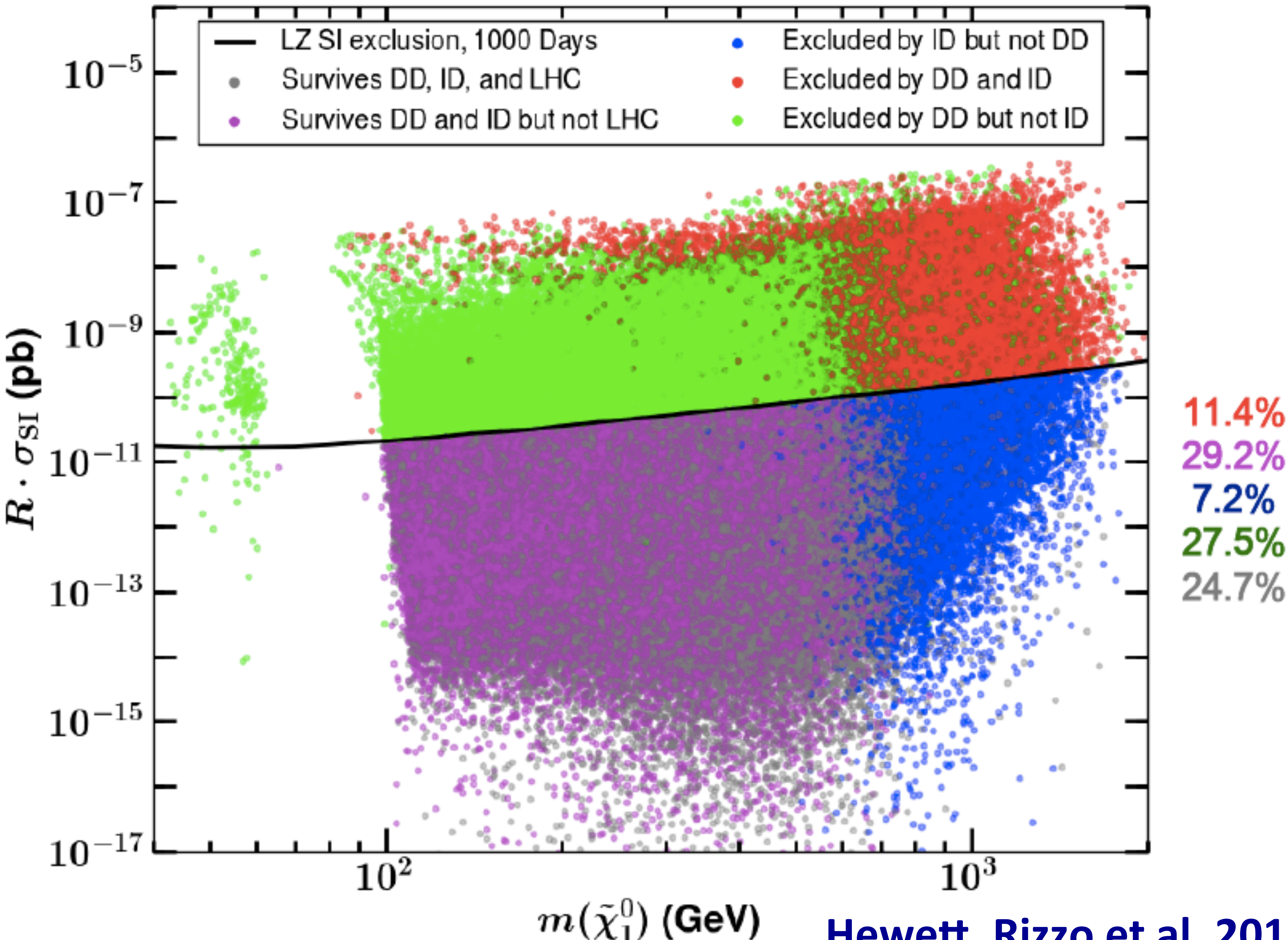
DM COMPLEMENTARITY: efficient annihilation in the early Universe implies today




CMS Preliminary
CMS, √s = 7 TeV, 5.1 fb⁻¹
CMS, √s = 8 TeV, 19.5 fb⁻¹
CoGeNT 2011
SIMPLE 2012
COUPP 2012
CDMS II
XENON100
Spin Independent, Vector Operator
χ-Nucleon Cross Section [cm²]
M_χ [GeV/c²]

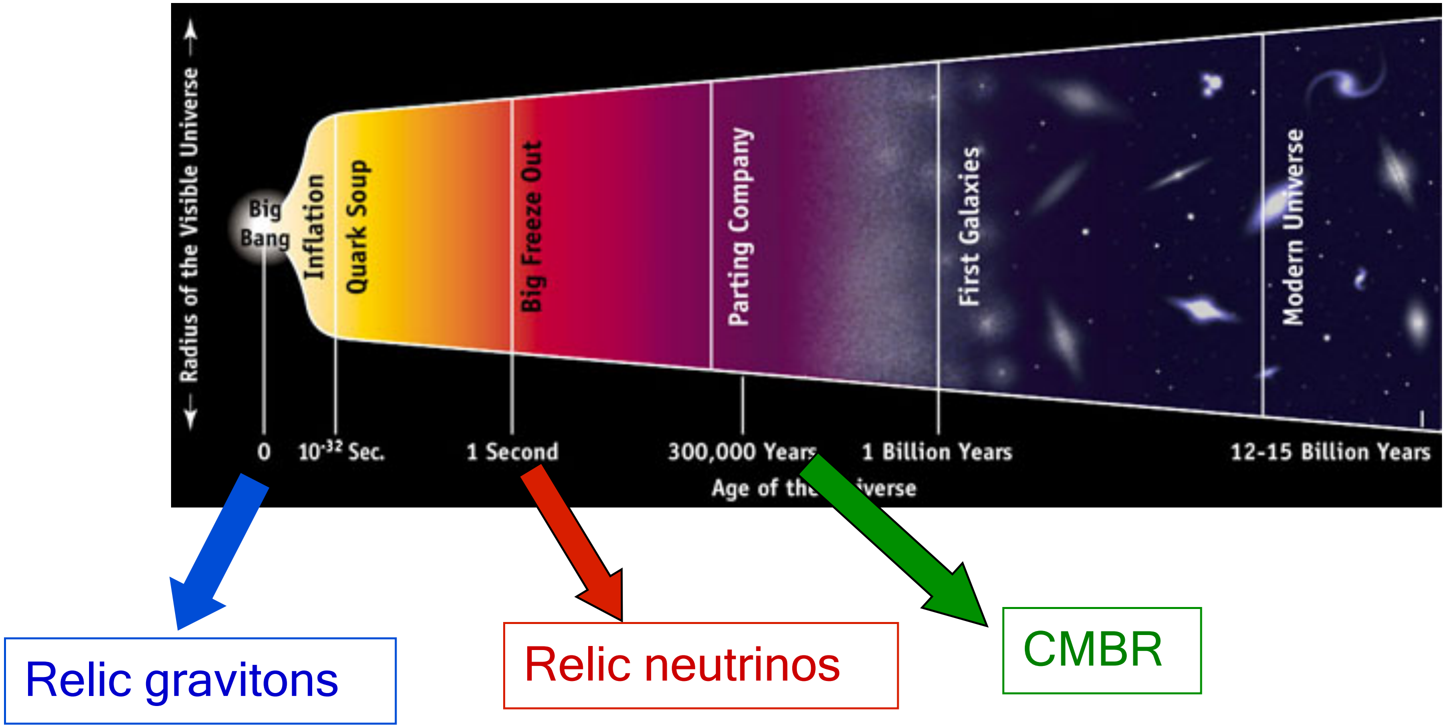

CMS Preliminary
√s = 8 TeV
∫L dt = 19.5 fb⁻¹
CMS 2012 Axial Vector
CMS 2011 Axial Vector
CDF 2012
SIMPLE 2012
CDMSII 2011
COUPP 2012
Super-K W⁺W⁻
IceCube W⁺W⁻
Spin Dependent
χ-Nucleon Cross Section [cm²]
M_χ [GeV/c²]

pMSSM models DD = LZ both SI + SD ID = FERMI + CTA



Hewett, Rizzo et al. 2013

Relic Stochastic Background



- Imprinting of the early expansion of the universe
- Correlation of at least two detectors needed

2nd GENERATION:
DISCOVERY AND ASTRONOMY

2nd generation detectors:
Advanced Virgo, Advanced LIGO

GOAL:

sensitivity 10x better →

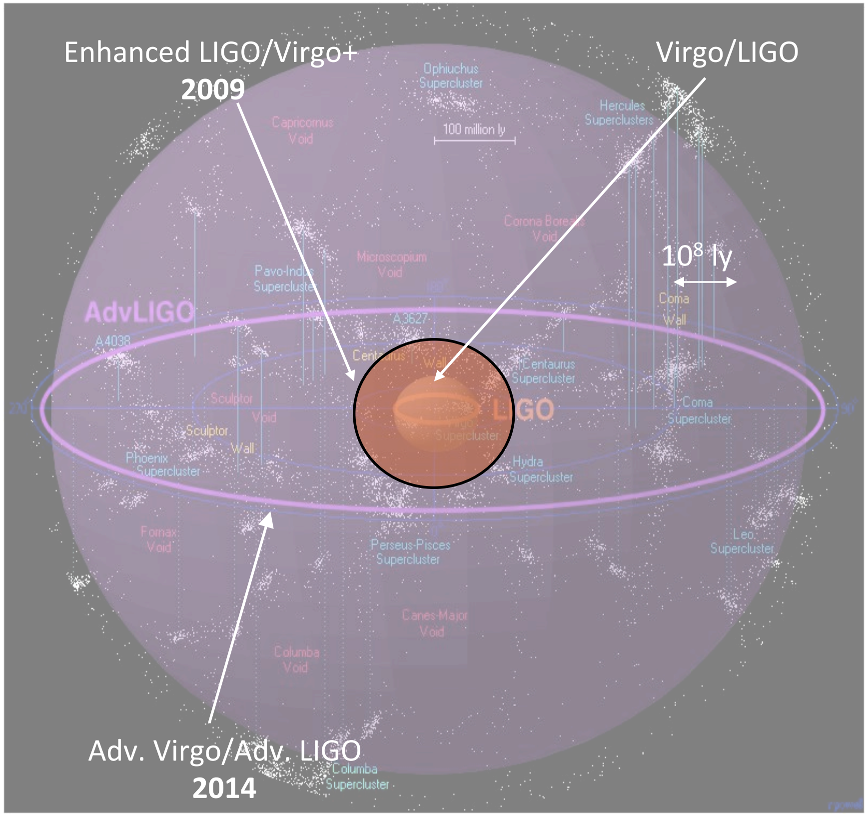
look 10x further →

Detection rate 1000x larger

NS-NS detectable as far as 300 Mpc

BH-BH detectable at cosmological distances

10s to 100s of events/year expected!

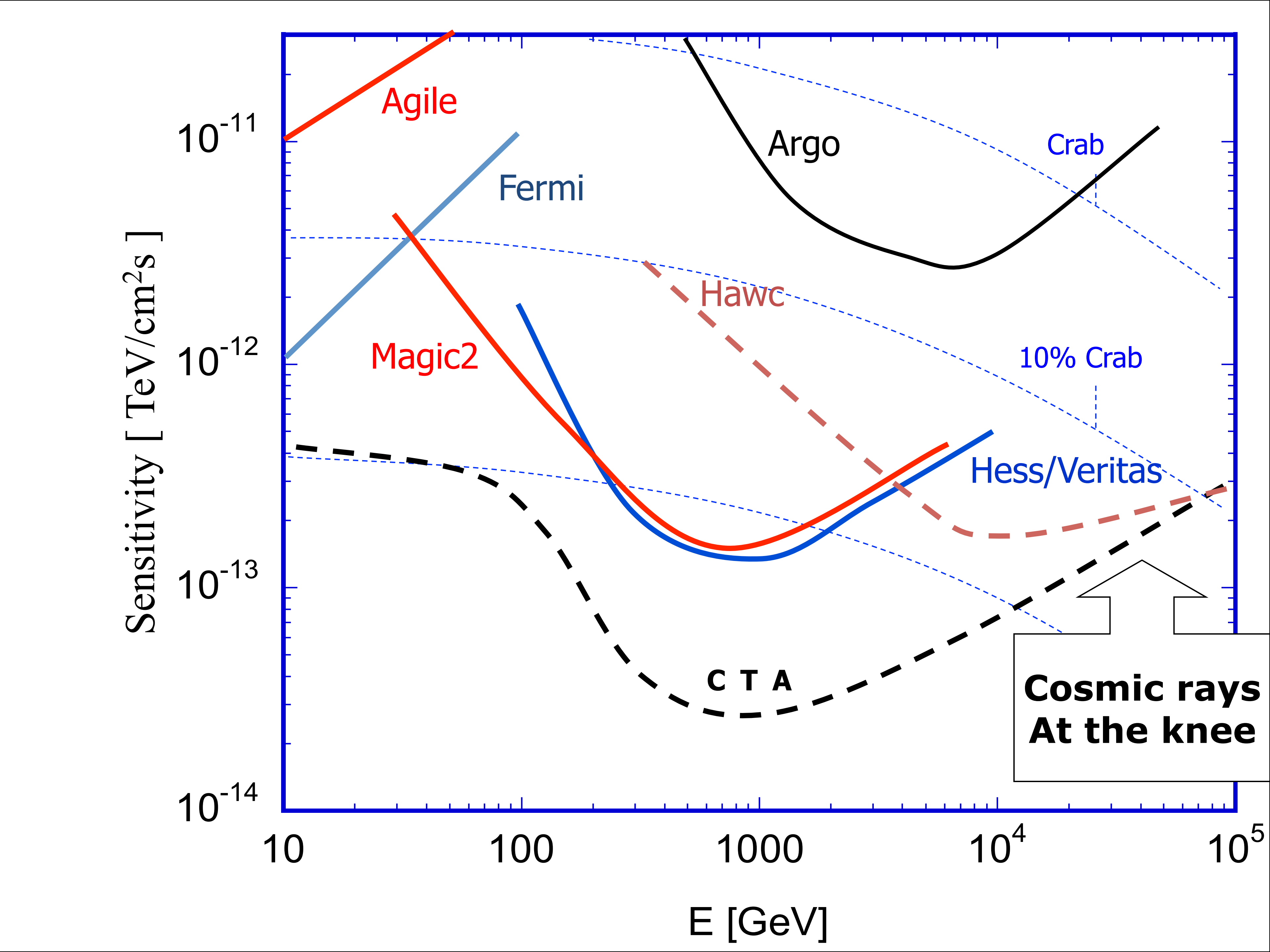


Credit: R.Powell, B.Berger

Post-Higgs Depression? No, thanks just the opposite....

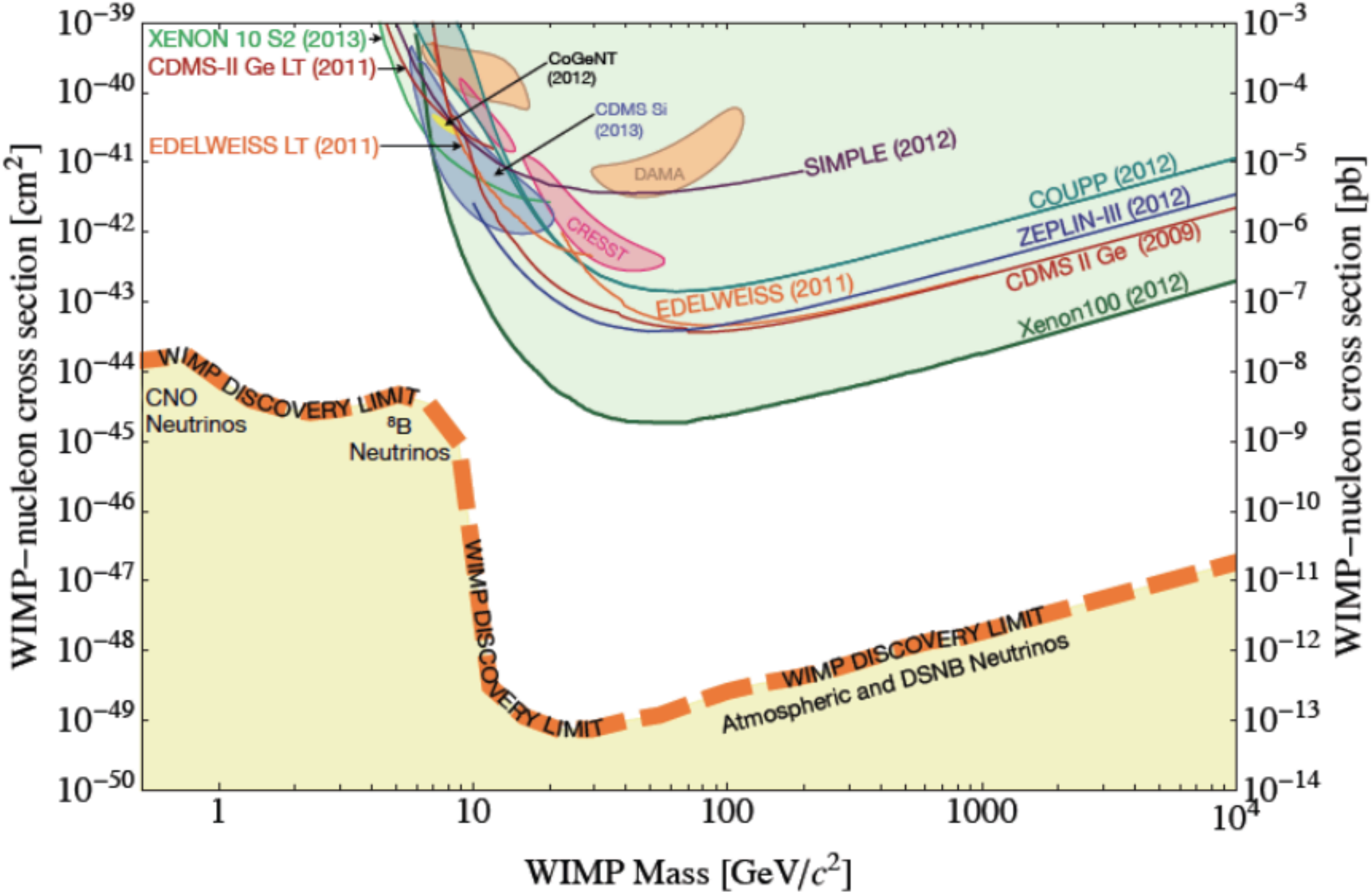
- **If the naturalness issue is indeed a relevant issue, the fact that we discovered a light higgs means that there MUST EXIST some mechanism stabilizing its mass and this mechanism NECESSARILY ENTAILS THE PRESENCE OF SOME FORM OF NEW PHYSICS AT THE ELECTROWEAK SCALE**
- Time to get ready (joint exp.-theor. effort) for the new results **in high energy, high intensity, neutrino physics, gravitational waves, cosmic radiation, dark matter and dark energy searches**

BACK-UP SLIDES



Agile
Fermi
Magic2
Argo
Crab
Hawc
10% Crab
Hess/Veritas
C T A
Cosmic rays
At the knee
Sensitivity [TeV/cm²s]
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10
100
1000
10^4
10^5
E [GeV]

Spin-Independent Cross Section: Current Experiment Results



so far: ~3 years / order of magnitude

THE FATE OF LEPTON NUMBER

L VIOLATED → ν Majorana ferm.

L CONSERVED → ν Dirac ferm. (dull option)

$h\, \bar{\nu}_L H\, \nu_R \rightarrow m_\nu = h \langle H \rangle$ $M_\nu < 5$ eV $\rightarrow h < 10^{-11}$

EXTRA-DIM. ν_R in the bulk: small overlap?

SMALLNESS of m_ν

↓

PRESENCE OF A NEW PHYSICAL MASS SCALE

NEW HIGH SCALE / NEW LOW SCALE

SEE - SAW MECHAN.

Minkowski; Gell-Mann, Ramond, SlansKy, Vanagida

↓

ν_R ENLARGEMENT OF THE FERMIONIC SPECTRUM

$M \nu_R \nu_R + h\, \bar{\nu}_L \phi\, \nu_R$

	ν_L	ν_R
ν_L	~O	$h \langle \phi \rangle$
ν_R	$h \langle \phi \rangle$	M

LR Models?

MAJORON MODELS

Gelmini, Roncadelli

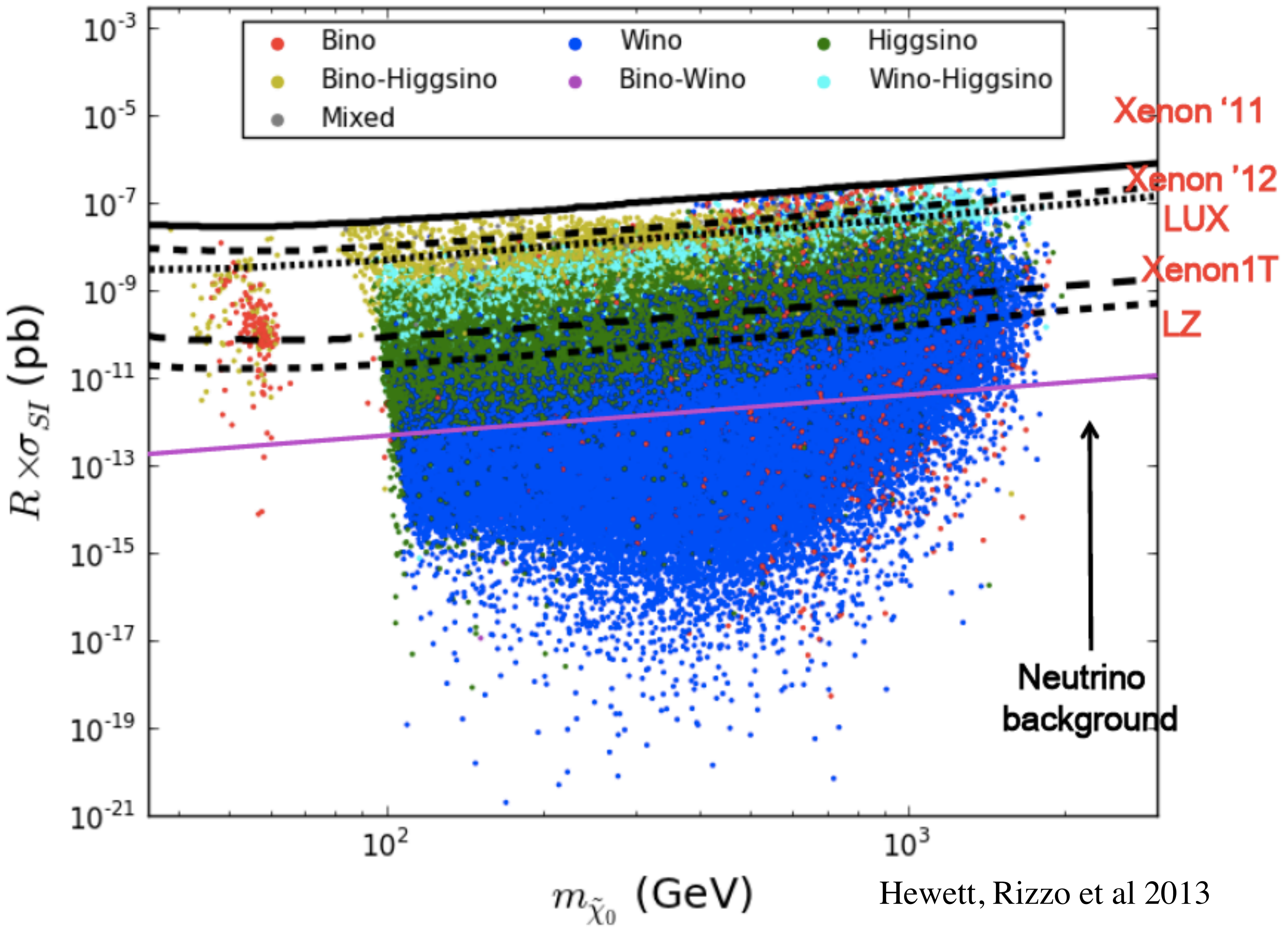
↓

Δ ENLARGEMENT OF THE HIGGS SCALAR SECTOR

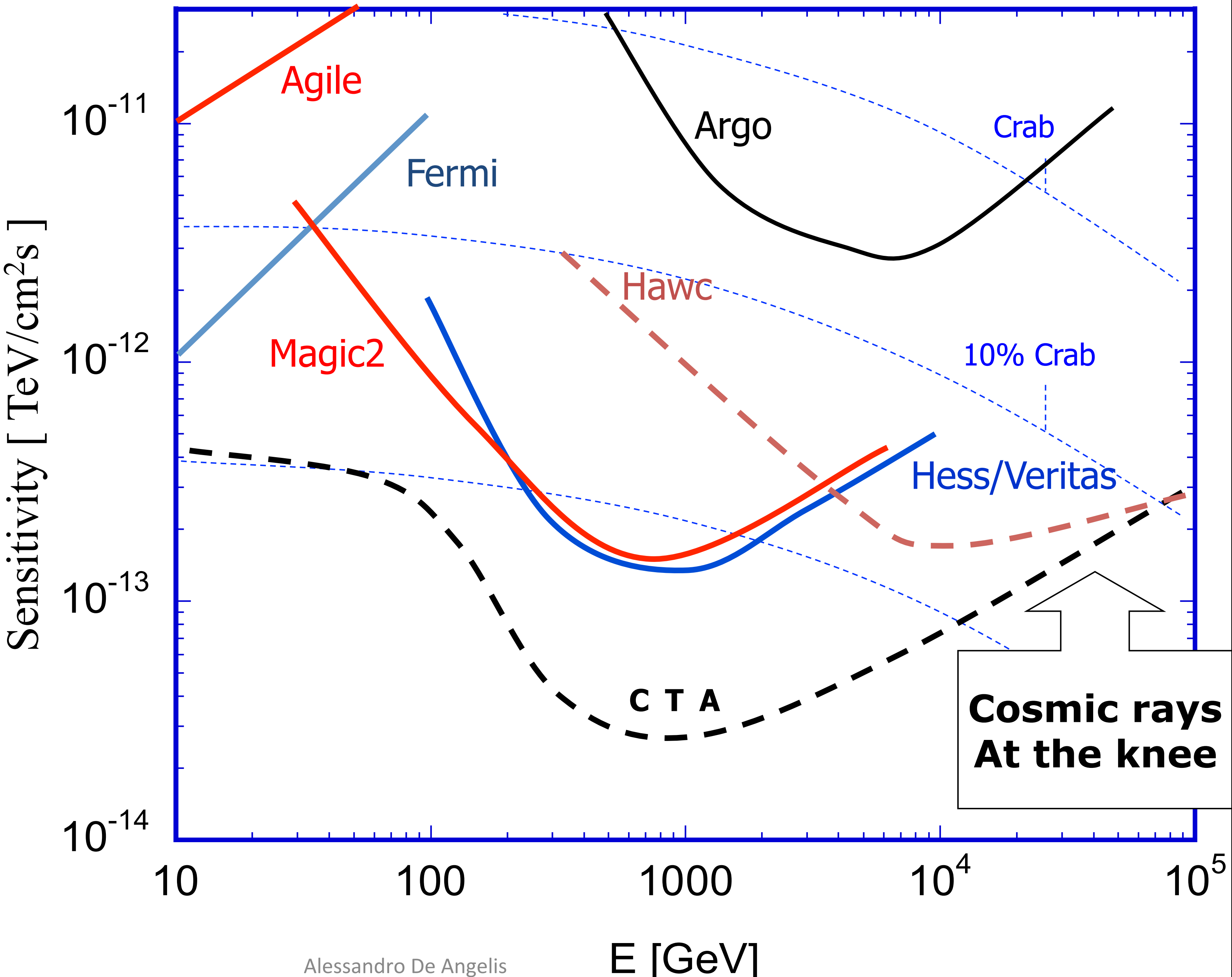
$h\, \nu_L \nu_L\, \Delta$

$m_\nu = h \langle \Delta \rangle$

N.B.: EXCLUDED BY LEP!

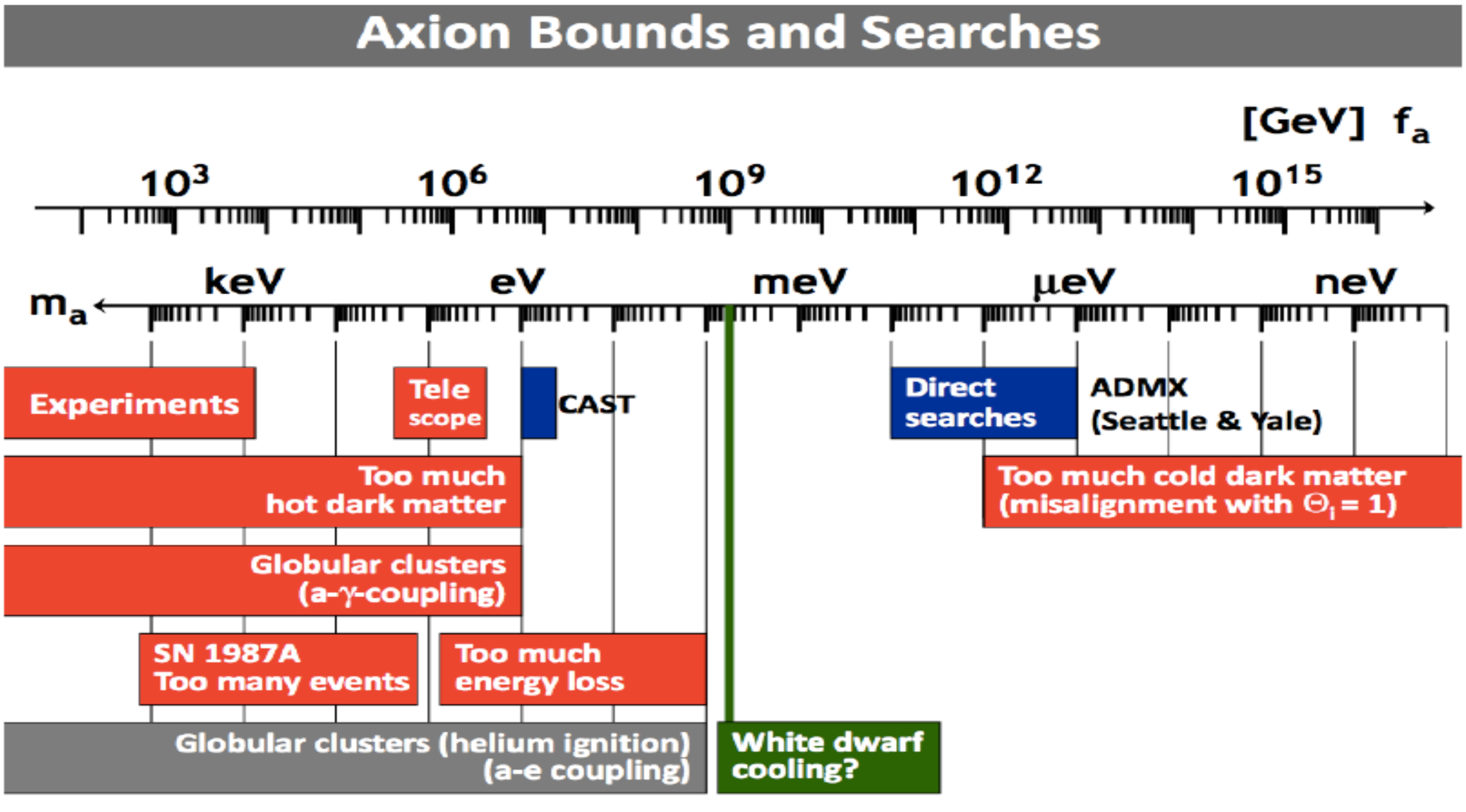


Hewett, Rizzo et al 2013

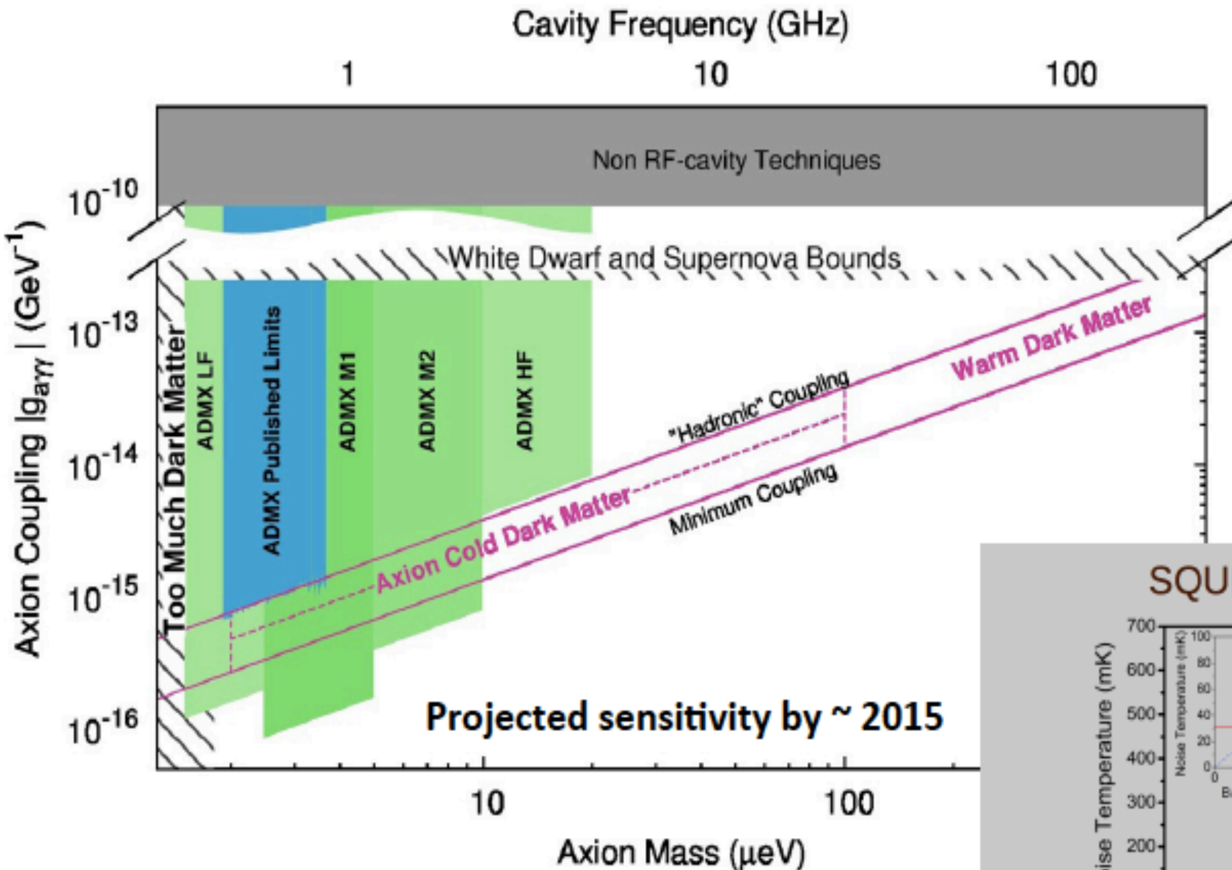


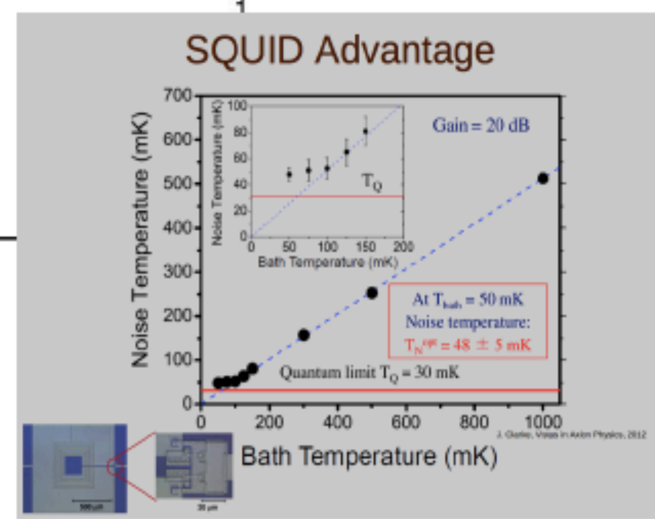
Alessandro De Angelis

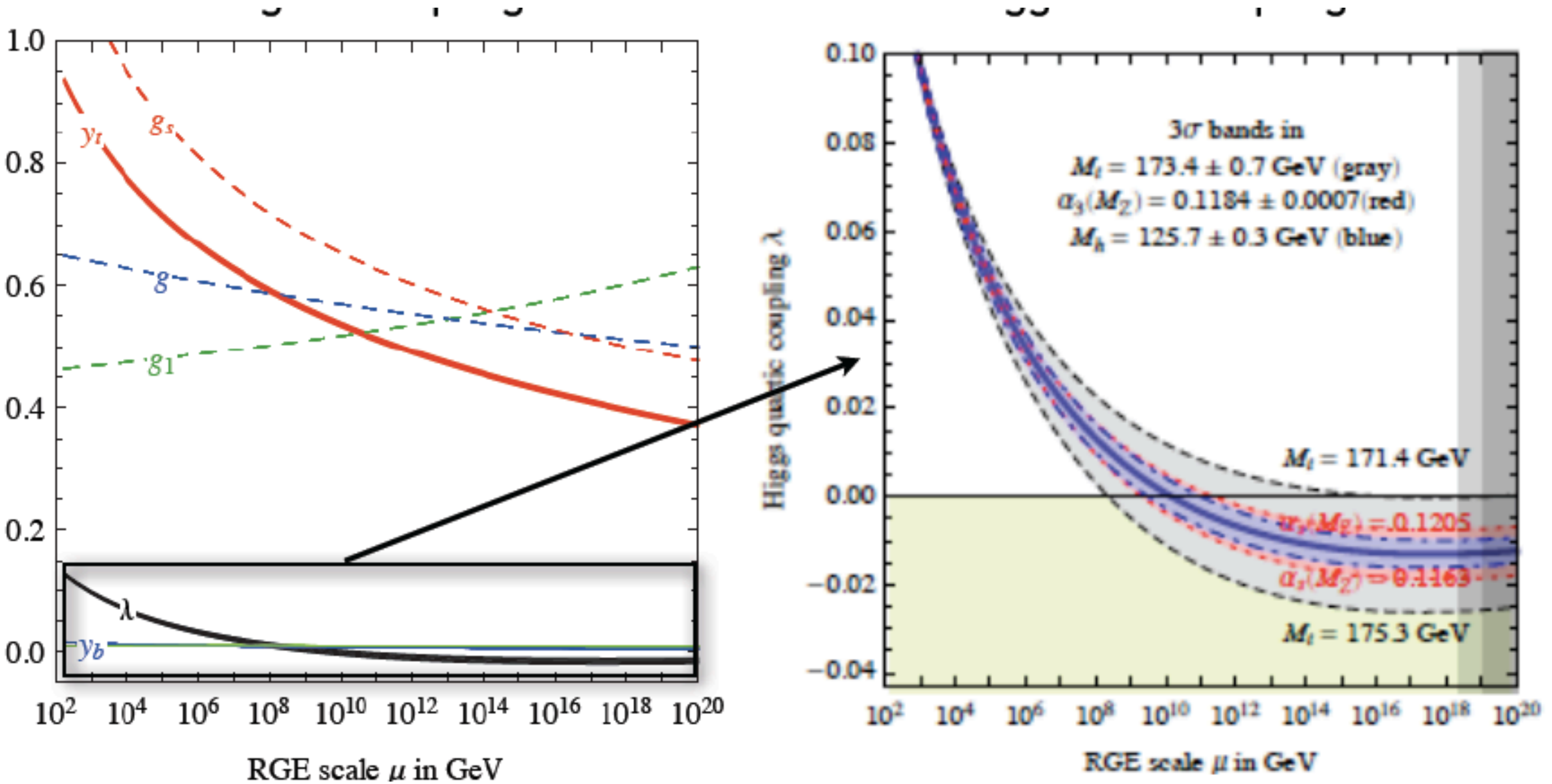
Keep in mind: we don't know at all what DM is made of ! Alternatives to WIMPs – for instance, AXIONS



ADMX achieved and projected sensitivity





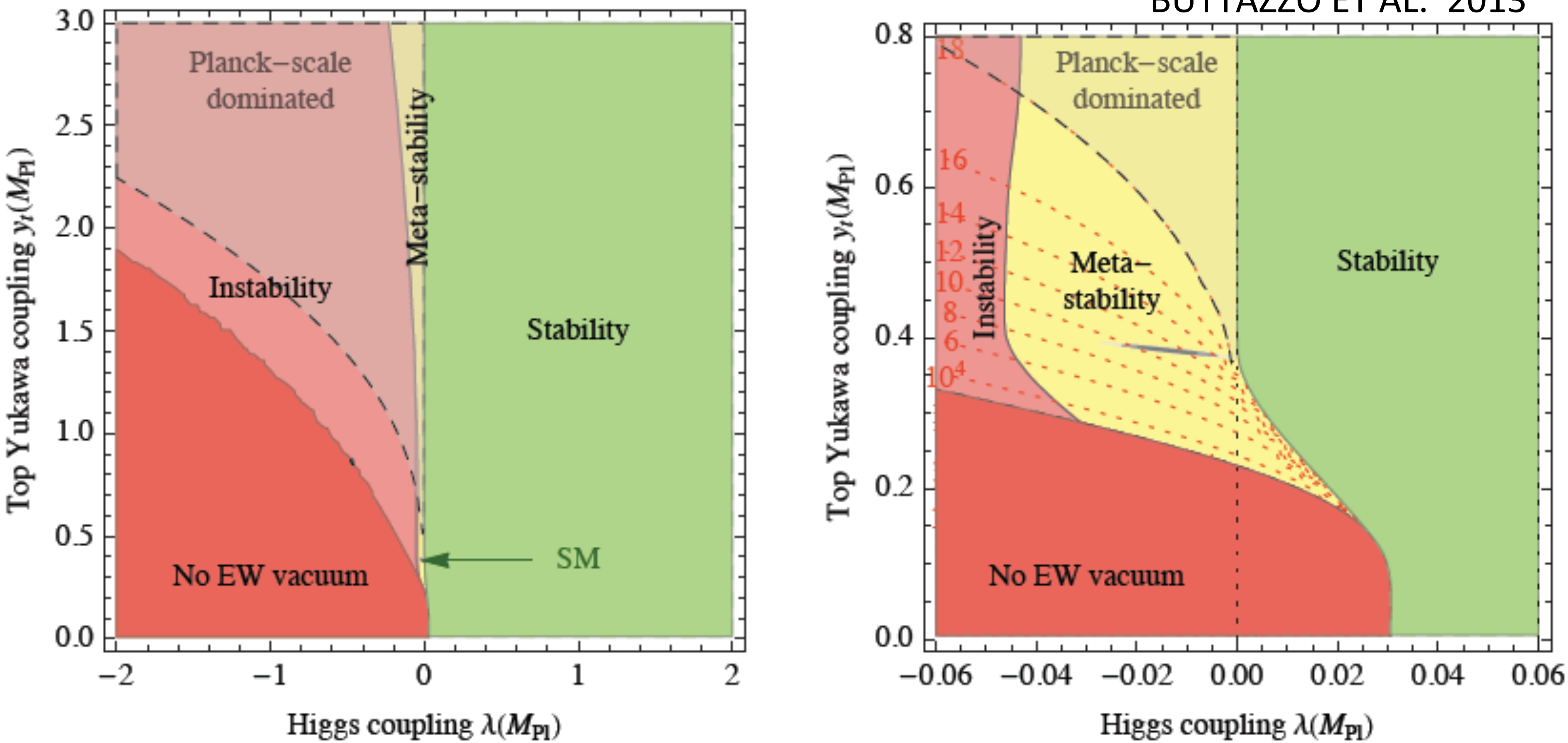


Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia 2013

For previous works: Krive, Linde ‘76; Krasnikov ‘78; Maiani, Parisi, Petronzio ‘78; Cabibbo et al ‘79; Lindner ‘86; Altarelli, Isisdori ’96; Ellis et al 2009; Shaposhnikov et al ’12; Elias-Miro’ ‘et a ‘’12; …..
Degrassi, Di Vita, Elias-Miro, Espinosa, Giudice, Isidori, Strumia ‘12

IF SM VALID UP TO M_{PLANCK} → **M_H formidable telescope to sneak into unexplorable energies…**

BUTTAZZO ET AL. 2013



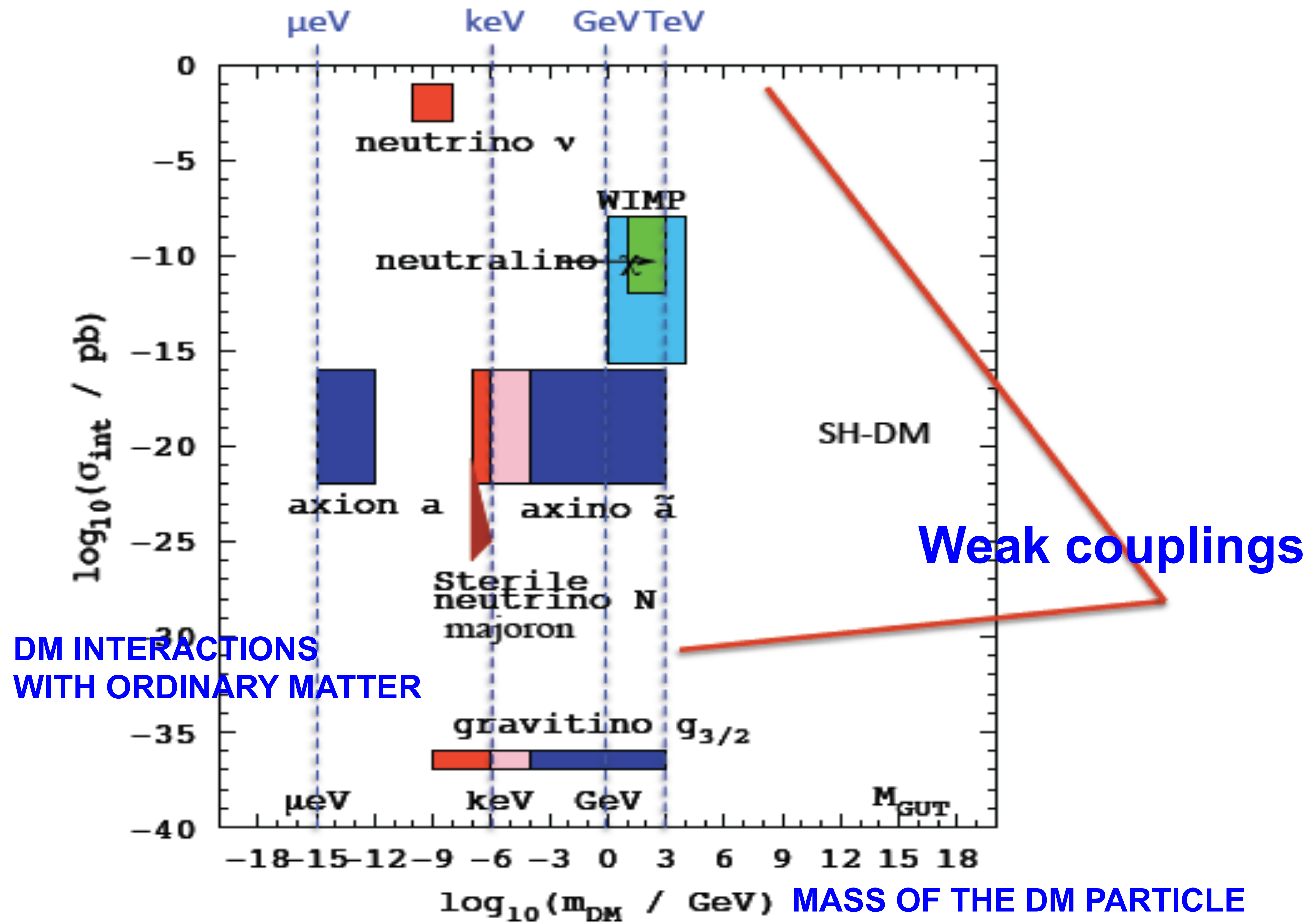
The Universe looks very close to **CRITICALITY**

ON THE IMPORTANCE OF PRECISELY MEASURING HIGGS and TOP MASSES

DEGRASSI ET AL

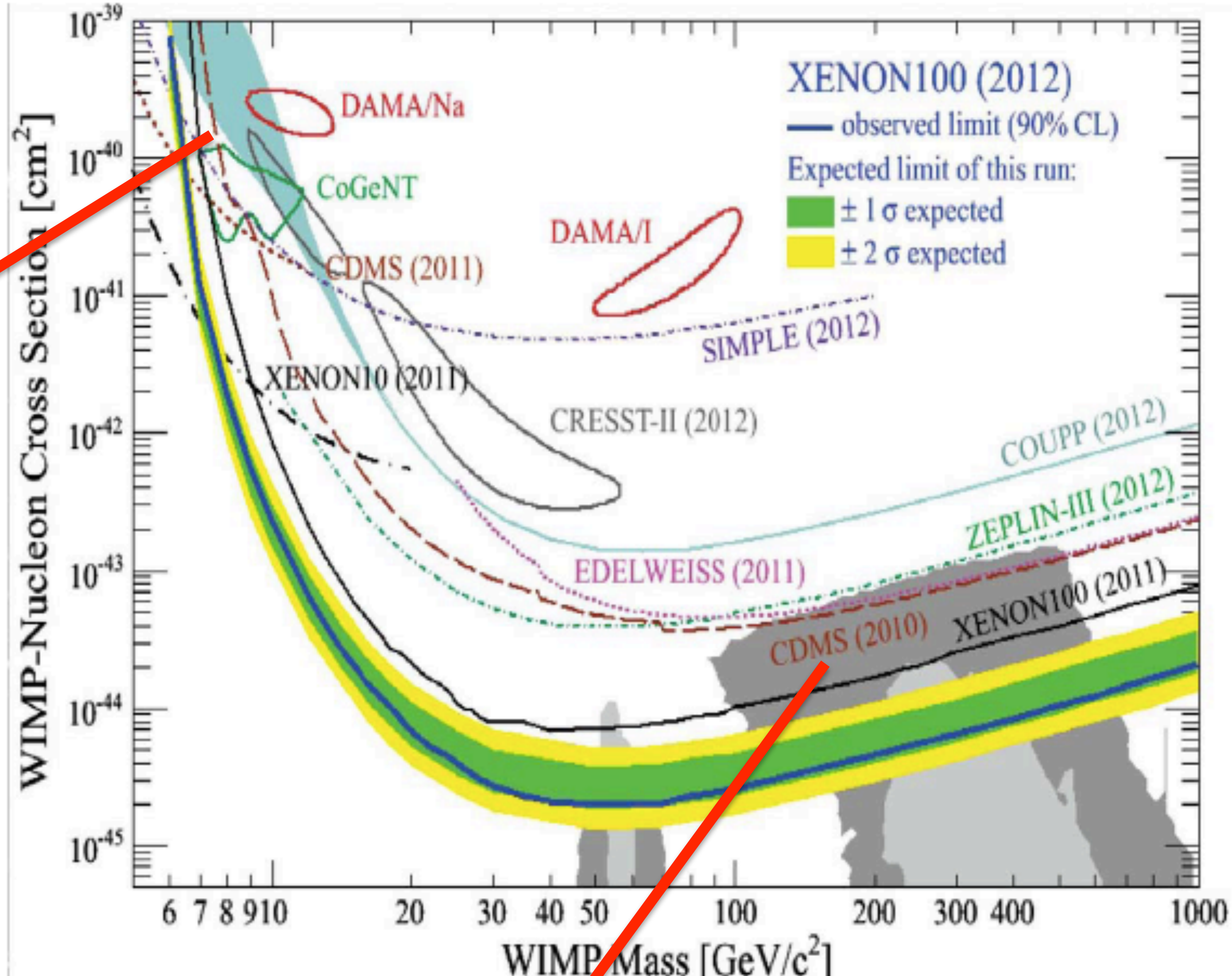
Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	± 1.4 GeV
α_s	experimental uncertainty in α_s	± 0.5 GeV
Experiment	Total combined in quadrature	± 1.5 GeV
λ	scale variation in λ	± 0.7 GeV
y_t	$\mathcal{O}(\Lambda_{QCD})$ correction to M_t	± 0.6 GeV
y_t	QCD threshold at 4 loops	± 0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	± 0.2 GeV
Theory	Total combined in quadrature	± 1.0 GeV

INTRINSIC DIFFICULTY TO "DEFINE" WHAT THE TOP MASS IS AT A **HADRON COLLIDER** WITH UNCERTAINTY ≤ 1 GeV

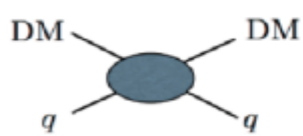

μeV
keV
GeV
TeV
neutrino ν
WIMP
neutralino χ
SH-DM
axion a
axino ã
Weak couplings
Sterile
neutrino N
majoron
DM INTERACTIONS
WITH ORDINARY MATTER
gravitino $g_{3/2}$
μeV
keV
GeV
M_{GUT}
0
−5
−10
−15
−20
−25
−30
−35
−40
−18 −15 −12 −9 −6 −3 0 3 6 9 12 15 18
$\log_{10}(\sigma_{int}$ / pb)
$\log_{10}(m_{DM}$ / GeV)
MASS OF THE DM PARTICLE

<u>Low-mass region</u>:
either unexplained backgrounds in DAMA, CoGeNT, and CRESST-II, …
or
… other experiments do not understand low recoil energy calibration, …
or
… can't compare different experiments

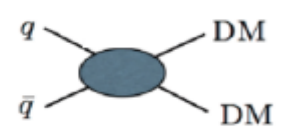
Kolb SUSY2012



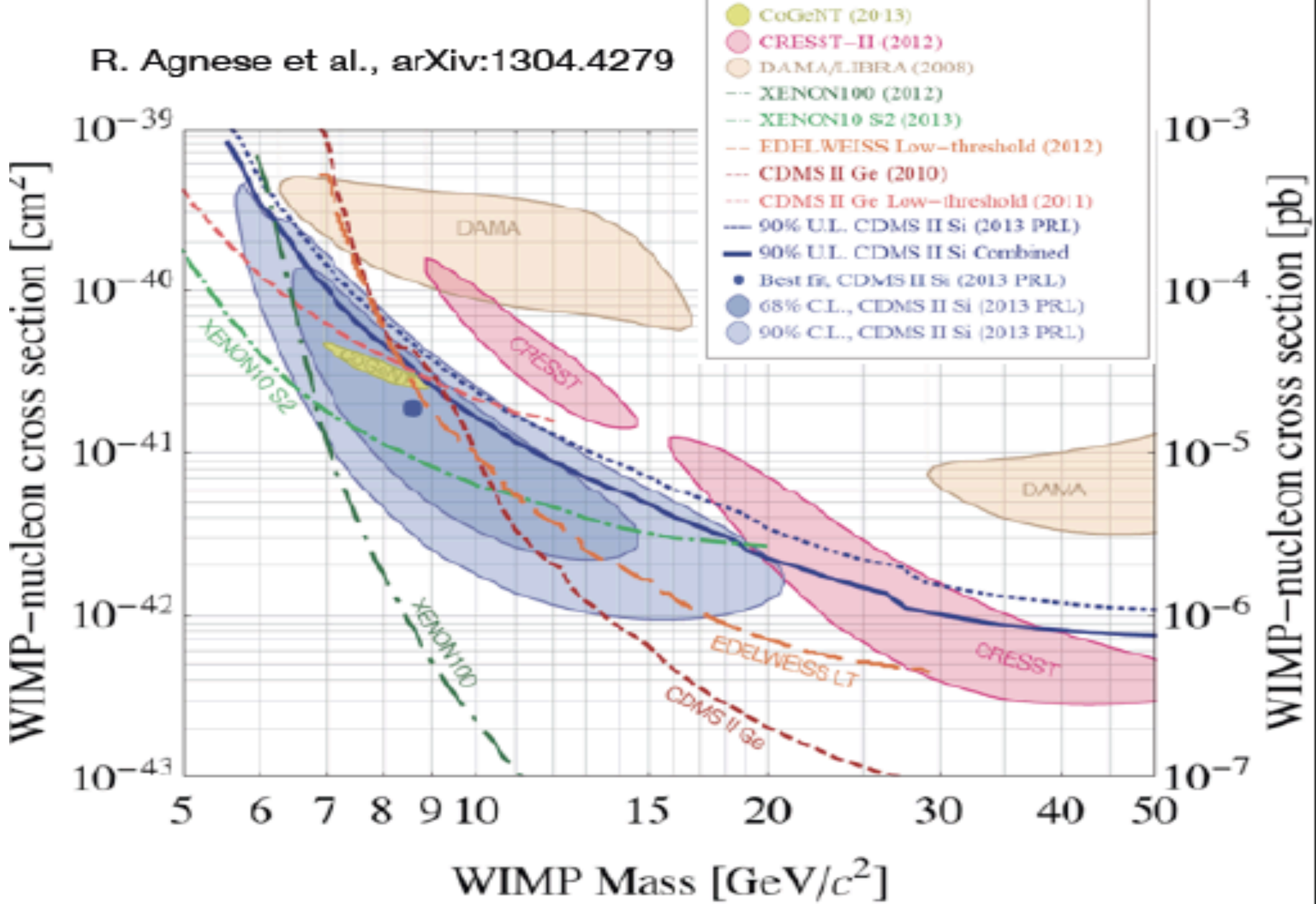
Relevant to intensify the efforts here: ex. **asymmetric DM** with **DM particles of mass~ baryon mass given that ρ_{DM} not much different from ρ_B**



Direct Detection (t-channel)

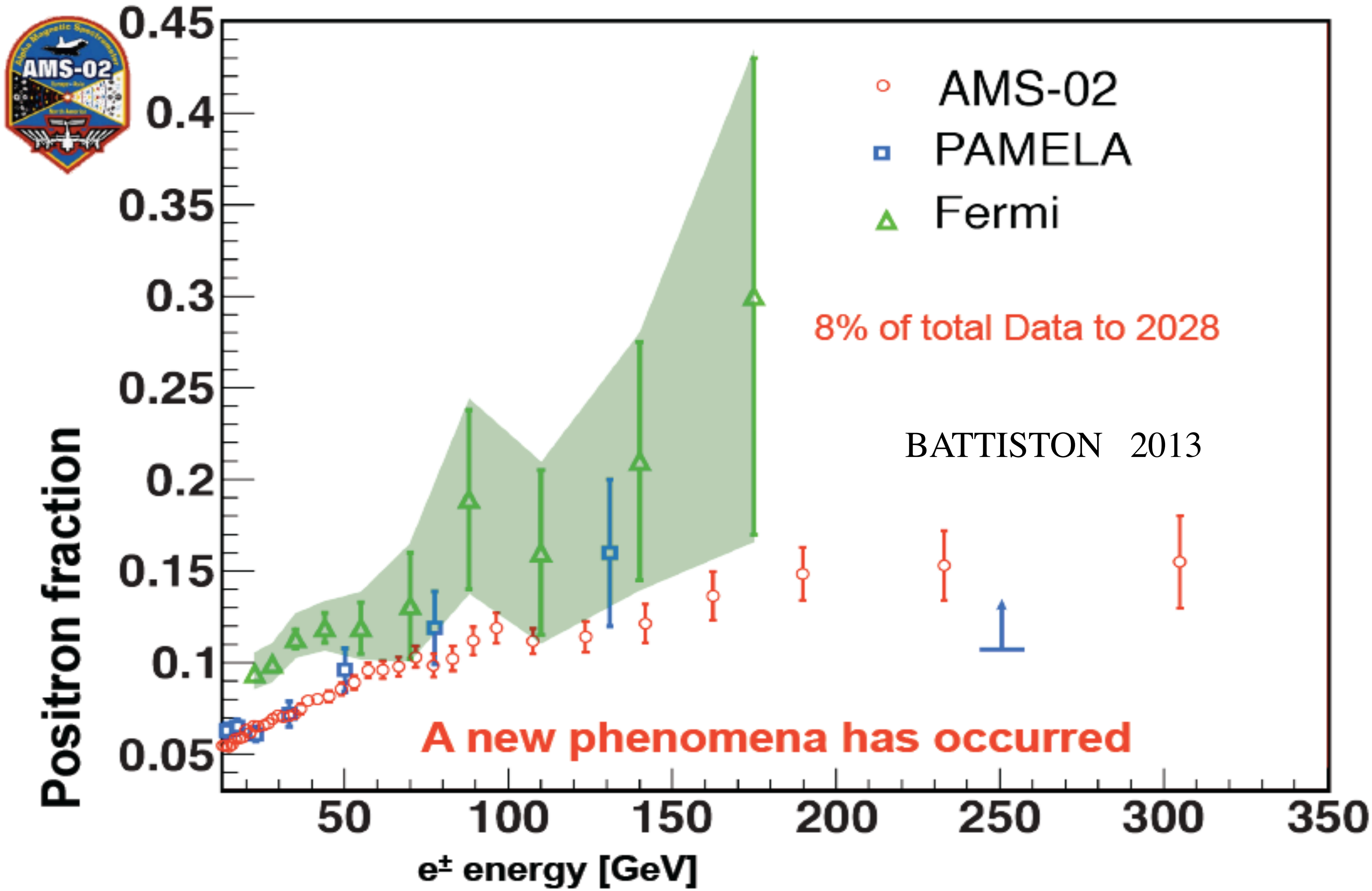


Collider Searches (s-channel)

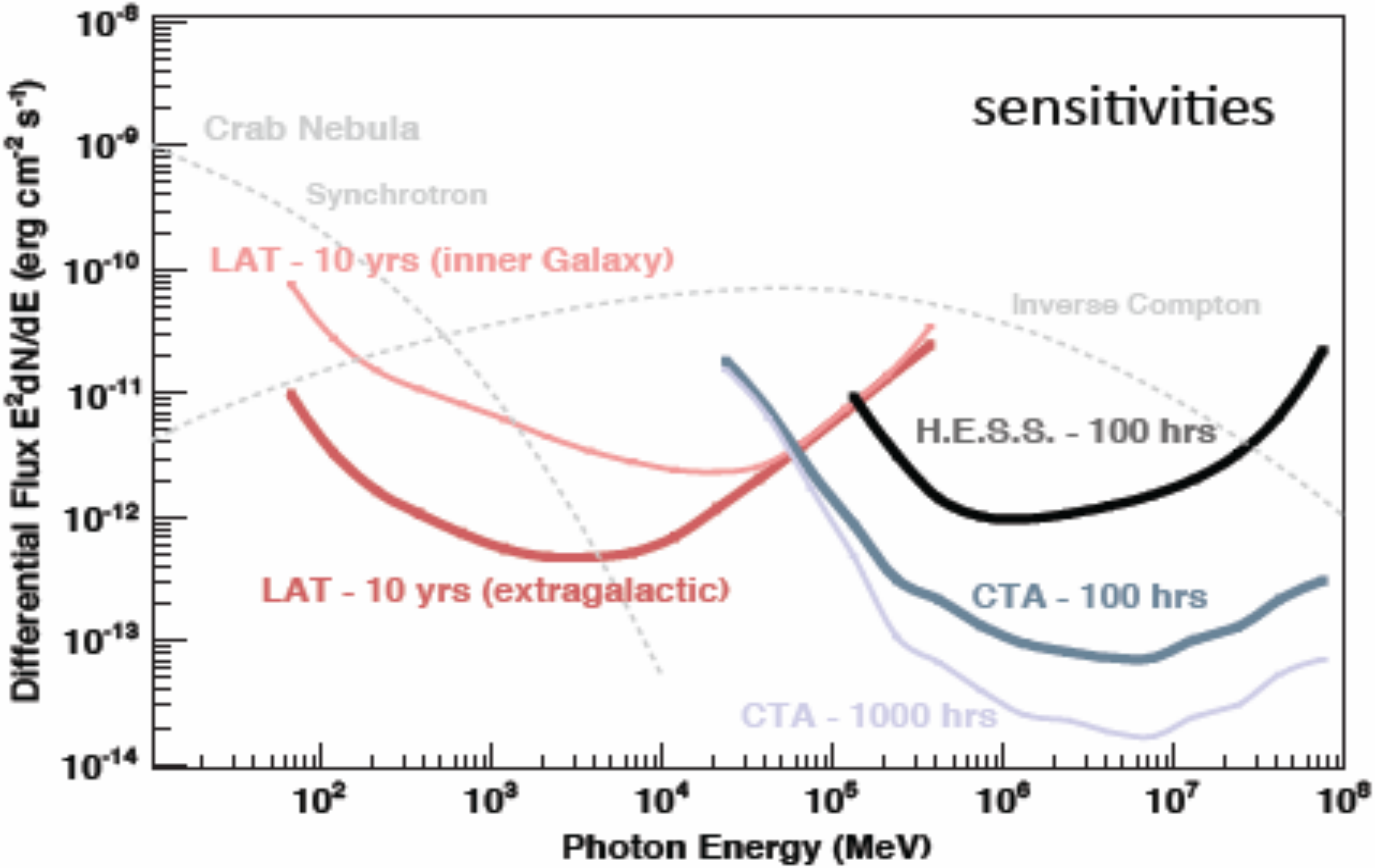


RELEVANCE OF THE DAMA-LIBRA RESULT– IMPORTANCE OF AN INDEPENDENT VERIFICATION (hard to reach the same level of sensitivity)

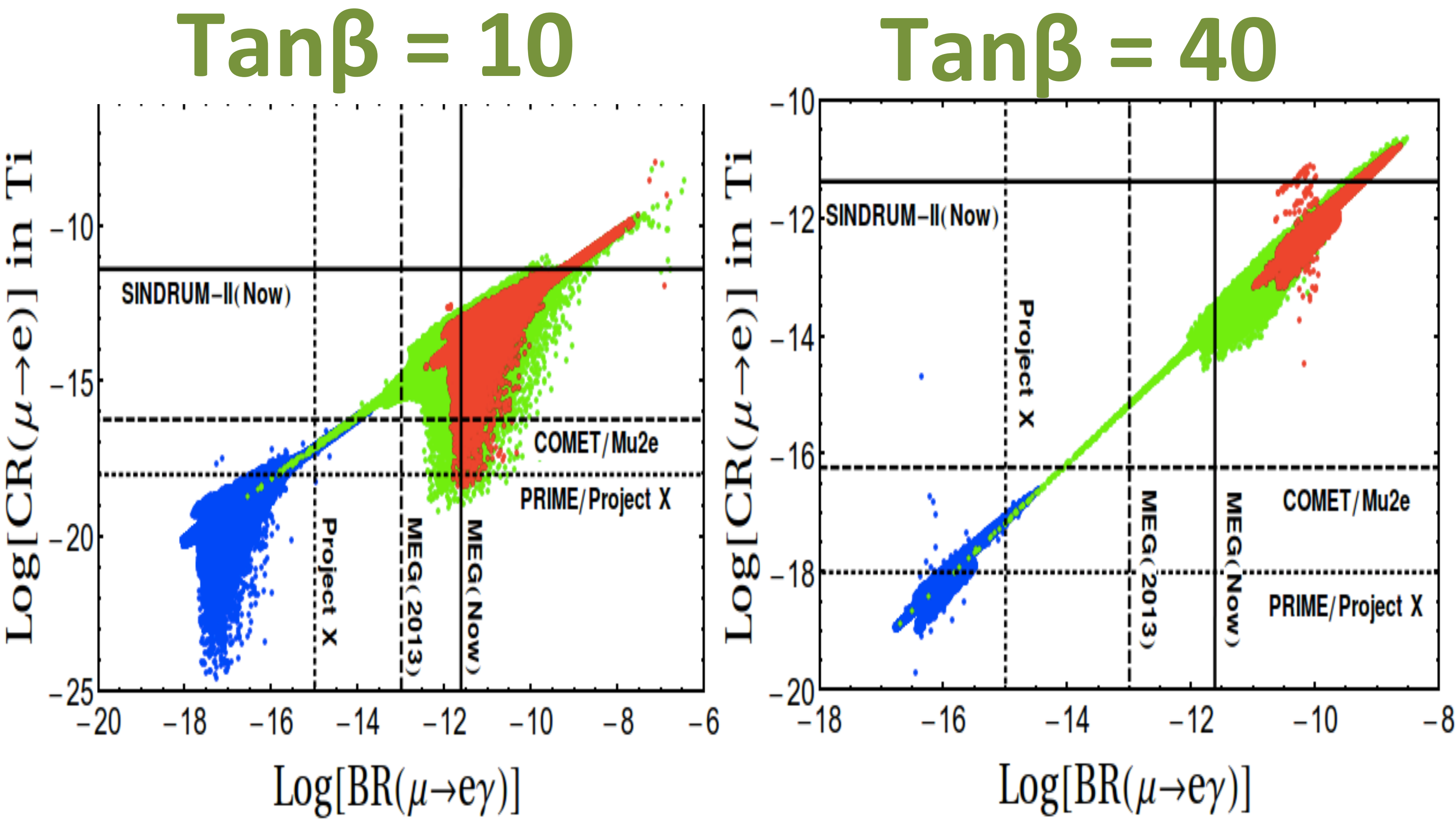
INDIRECT SEARCHES FOR DM



GAMMA – ASTRONOMY FROM EARTH AND SPACE



μ – e conversion vs μ → eγ



Is the DM a portal to new physics beyond the SM? (I)

- DM: most of the gravitationally clusterized form of energy of the Universe that we call MATTER is of non-baryonic nature, i.e. **non-baryonic DM exists**, and **it is by itself new physics**, i.e. it is made of particle(s) which are not present in the SM particle spectrum
- **Is (are) the mass(es) of the DM particle(s) at the electroweak scale**, i.e. of O(1TeV), or is the DM scale not correlated at all with the elw. scale?